

# HPCB

## High Performance Commercial Building

### Control System Design Guide

*Element 5—Integrated Commissioning and Diagnostics*  
*Project 2.1 Commissioning and Monitoring for New Construction*

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**May 2003**



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## Acknowledgements

This work has been supported by:

- The California Energy Commission's (CEC) , Public Interest Energy Research Program, under Contract No. 400-99-012.
- The Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Building Technologies Program of the U.S. Department of Energy (DOE) under Contract No. DE-AC03-76SF00098.

Special thanks to Martha Brook (CEC) and David Hansen (DOE). Appreciation is extended to Marti Frank of PECI for her assistance.

Technical review was provided by the following experts:

Gretchen Coleman, P.E., Engineering Economics, Inc. (EEI)

Karl Stum, P.E., CH2M HILL

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# Chapter 1: How to Use the Design Guide

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## 1.1. Overview

The *Control System Design Guide* (Design Guide) provides methods and recommendations for the control system design process and control point selection and installation. Control systems are often the most problematic system in a building. A good design process that takes into account maintenance, operation, and commissioning can lead to a smoothly operating and efficient building. To this end, the Design Guide provides a toolbox of templates for improving control system design and specification.

HVAC designers are the primary audience for the Design Guide. The control design process it presents will help produce well-designed control systems that achieve efficient and robust operation. The spreadsheet examples for control valve schedules, damper schedules, and points lists can streamline the use of the control system design concepts set forth in the Design Guide by providing convenient starting points from which designers can build.

Although each reader brings their own unique questions to the text, the Design Guide contains information that designers, commissioning providers, operators, and owners will find useful.

## 1.2. Chapter Summaries

**Chapter 2 Control System Design Process** A bird's eye view of the design process details the different demands placed on designers, contractors, and owners. Topics covered include the importance of system diagrams, detailed sequences of operation, points lists, and detailed specifications. Spreadsheet templates are provided to streamline the design and specification process for control points, valves, and dampers. Completed spreadsheet templates are also included as examples.

**Chapter 3 Selection and Installation of Control and Monitoring Points** The guidelines will help designers make decisions about control and monitoring point selection to improve efficiency and control over the life of the building. Detailed discussion of common sources of measurement error helps designers avoid these problems in their design and helps commissioning providers interpret inaccuracies in field measurements. Recommendations for selecting and installing temperature, humidity, pressure, and flow sensor technologies guide both designers and commissioning providers through the ever-changing world of sensors. Recommendations for interfacing points to the building automation system (BAS) includes discussion of point naming conventions, settings, alarms, display graphics, and trending.

**Chapter 4 System Configurations** This chapter describes twelve common air handling system configurations and recommends the monitoring and control point requirements associated with each configuration. These points lists spreadsheets can be used by designers and commissioning providers as a starting point on their own projects.

## 1.3. Getting Around the Guide

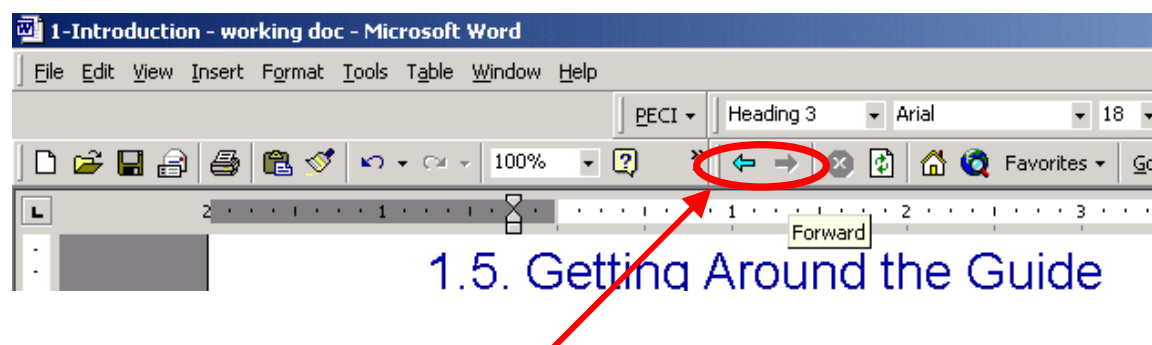
While the Control System Design Guide contains a large amount of information in each chapter, this information can be easily accessed using three features: the table of contents, the web toolbar, and hyperlinks. The Design Guide is intended to be used electronically with these navigation features, rather than printing out the entire document. As needed, individual chapters and supporting documents can be printed for ease of use.

### 1.3.1. Using the Table of Contents

The table of contents for the Design Guide is titled, “TableofContents\_DG.doc”. It provides links to each of the four chapters. Clicking on the chapter title opens the chapter as a separate document. Within each chapter, you will find another table of contents. The chapter’s table of contents contains links to each section of the chapter, figures, tables, and equations.

### 1.3.2. Web Toolbar Navigation

The easiest way to navigate through the Design Guide is to use each chapter’s Table of Contents, along with the “back” button on the Web Toolbar. Figure 1.1 below identifies the back button, a left-facing blue arrow. The back button allows you to return to your previous location in the document, much as the back button on your web browser returns you to the previous web page.



**Figure 1.1 Identifying the Web Toolbar Navigation Arrows**

If the back button is not currently showing in your toolbar, you can add it by following these steps:

- 1** Go to the **Tools** menu, click on **Customize...**
- 2** In the **Toolbars** tab, check ‘**Web**’ to add this toolbar.
- 3** The Web toolbar will show up at the top of your screen, including the navigation arrows

Try using the back button in the following exercise:

- Begin with the Table of Contents document (TableofContents\_DG.doc)
- Click on any chapter – then you’ll see the table of contents for that chapter
- Click on any topic in the chapter’s Table of Contents and it will take you to that section
- To get back to the chapter’s Table of Contents, click the back button.
- To get back to the Design Guide’s table of contents, click the back button again.

You will also notice that the “forward” button (a right-facing blue arrow) appears after you use the back button. The forward button has a similar navigational effect – it returns you to the previous location in the document. The back button and forward button will help you explore the chapters of the Design Guide and still get you back to the primary navigation point – the Table of Contents.

### 1.3.3. Hyperlinks

Hyperlinks embedded throughout the Design Guide can be used to quickly access information. Clicking on a hyperlink will take you directly to the topic of interest. In the Design Guide, the hyperlinks are formatted in two ways, with examples from Chapter 2 shown below:

- **Blue Text With Underline**

*Example:* Alarms that involve comparison or calculations are often called “smart alarms”, which are described in more detail in Section [3.6.4: Programmable Alarms](#).

- **Blue Button:**

*Example:*



**This spreadsheet is a blank version of Figure 2.3 and Figure 2.4. You can use this spreadsheet as a starting point for valve schedules on your projects.**

Also remember that each line in the Table of Contents document as well as in each chapter’s Table of Contents has an embedded hyperlink.

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## 2.1. Introduction

This chapter provides an overview of a control system design process that has been used successfully to provide well-functioning control systems for numerous commercial, institutional, and industrial HVAC projects. While the process outlined in this chapter is not the only viable method for successful control system design, it does provide a useful template that illustrates important design elements. These elements need to be addressed directly and proactively to ensure that the design intent is met. Otherwise, they will be addressed by circumstance or default with results that are far from the desired outcome. The Design Guide uses the template to focus on why and how to specify the elements it contains, thereby guiding designers who wish to modify their existing processes to reflect some or all of the template's components.

Projects with inadequate control system designs often require additional effort and capital outside of the project budget to meet design intent. Some people may argue that providing detailed specifications will add cost to the project in an industry where budgets are already tight. In this chapter, we advocate that:

- The capital expended up front during design to ensure the details are adequately addressed will typically be orders of magnitude less than the capital expended subsequent to construction to correct the defects and pay for the inefficiencies that result from lack of design detail.
- The costs can be controlled by standardizing the proposed methods and by directing the task to those in the best position to accomplish it.

For example, to obtain a functional economizer, someone has to size the dampers, make configuration decisions, and select actuators. Even if the damper is not properly sized, someone will have to make those decisions when it is ordered or installed. While it may take someone with experience to properly size the damper compared to simply ordering it, the time required for the engineering is minimal compared to the cost of modifying or replacing the dampers after they are installed and the operating cost penalties associated with poor performance. On some projects, the designer may be the best candidate for this role. On others, it may be the contractor. What matters is that someone is charged with the task and then held accountable for the results. With these issues in mind, we will start the chapter by examining the working environments for the parties with vested interest in a good control system design. By understanding these working environments, potential problems can be acknowledged and dealt with through a good control system design process.

## 2.2. The Dilemma

HVAC control systems are the central nervous system of the machine world. The most efficient, well-selected and installed mechanical equipment can be reduced to a problem-riddled, inefficient mechanical nightmare by a poor control system design. One would expect that developing the control system design and installation parameters would be a significant portion of the HVAC design process and that the design of the control system would start early in schematic design. Unfortunately, this process often does not occur, and the control system information is often added to the construction documents at the last minute. In addition, the control system design information is frequently structured in a manner that delegates much of the responsibility for the final product to the control contractor with very little project specific detail included in the contract documents. As a result, the control contractor must develop a price for a final product that is loosely defined in a competitive bidding environment. The result is often less than perfect, frustrating the designer, the contractor, and Owner with problems that can plague the project for its lifetime.

## 2.3. The Key Players

The key players in the dilemma described above are the HVAC designer, the control system contractor and the building owner. All three of the players have distinct but interrelated needs with regard to the design of the control system. The following sections bring the needs of each party to focus and identify the challenges that each party faces. With an understanding of these issues, the designer is in a good position to lead the efforts to ensure that a robust control system is installed that meets the needs of the owner.

### 2.3.1. The Designer's Requirements and Challenges

The rapidly evolving technology associated with current HVAC system design confronts designers with a multiplicity of control system requirements and challenges.

- **Time and Fee Restrictions** The technology employed in current building systems has rapidly advanced over the past several decades. At the same time, there are shorter design windows for development of these more complex designs. The fast-paced development and construction schedules and the interdisciplinary interactions required to implement sophisticated building technologies have resulted in the need for frequent meetings between the design team leaders, which has resulted in increased overhead while fees have not increased in a corresponding manner. The net effect is a decrease in the amount of time the design team leaders can devote to project technical development work. To solve this problem, they often delegate tasks to lower level staff that have less experience from which to draw to make crucial technical decisions. Delegating tasks to the contractors via performance specifications has become a common approach for control system design. Unfortunately, competitive bidding pressures often prevent control contractors from implementing the necessary level of quality. The contract language is so vague that it can be interpreted liberally at the expense of quality and performance. With dedication to writing control system technical specifications, designers can successfully create a level playing field for bidders to provide quality controls installations. Specifications are discussed in detail in Section [2.4.3](#).
- **Technical Expertise** The rapidly evolving field of direct digital control has left many HVAC designers feeling that they lack the knowledge required to develop a detailed

#### *Time Warp*

*In the late 90's a project engineer working on a surgery addition project for a 40's vintage hospital complex was reviewing old files from the original surgery construction project. In the course of reviewing these documents, he discovered that the design window for the original project was the same size as the time allowed to take the current project from concept to completion. Yet, the current project had far more complex issues to consider. The new surgery suite was constructed in a high-rise addition over an existing outpatient clinic that had to remain in service during construction. Compared to the 1940's construction, the project had more complex licensing standards, as well as more complex HVAC, electrical, and utility systems. To top it off, all systems had to be interfaced to the existing plant while it remained in service.*

control system design. Tight construction schedules and fee structures leave little time or money to support the training required to stay current with the details of control system hardware, programming, and architectural issues for a wide array of manufacturers and suppliers. As a result, many designers delegate many of the details of the control design to the contractors bidding the project, believing that they do not have the time, budget, or expertise to do otherwise. While this may be true with respect to the specific technical details of any given manufacturer's system, many important parameters related to the design of the control system are actually a function of HVAC requirements the designer is (or should be) familiar with. Examples of these parameters include set points and sequencing, control point locations, and sensor accuracy.

- **Minimize Field Installation and Start-up Problems** The HVAC designer has a vested interest in providing plans and specifications that minimize the field installation and start-up problems associated with their projects. Not only does this ensure that the intent of their design is fully realized, it also protects them from liability problems associated with systems that fail to perform to the Owner's expectations, and improves their ongoing client relationships. For HVAC systems, a good control design is key to successfully achieving the design intent of the project and efficient, reliable system operation. Designers who can develop methods that allow them to clearly and completely describe the control system requirements will be rewarded with systems that start up smoothly and operate reliably. The resulting bottom line will be happier clients, fewer field problems that rob valuable billable production time from other projects, improved client relationships that can foster repeat business and better fees, and reduced liability and exposure to litigation.

## 2.3.2. The Contractor's Requirements and Challenges

Control contractors operating in the current construction market find themselves faced with requirements and challenges that are directly related to those that the designer faces.

- **Time and Fee Restrictions** The control contractor must develop a low bid for a project based on the information available on the construction documents, usually within a short bid window. The portion of the project that the control contractor bids is technically complex with contractual and physical interfaces to virtually every other contractor working on the project's mechanical and electrical systems as well as some of the architectural trades. Much of the work associated with a DDC system involves the electrical trades, and many control companies require that their sales engineers perform a detailed electrical take-off for the project or obtain competitive pricing from electricians. The sales engineer or their subcontractors have to develop an understanding of the system architecture and the location of the points relative to the physical arrangement of the equipment on the project. The technical issues associated with the system's architecture and installation requirements will generally dictate the physical requirements for installing the system. If this information is not well-developed on the contract documents, then the sales engineer will need to develop it within the constraints of the available requirements.

In most cases, while the contractor is developing their bid, the project is still in a state of flux. Last minute changes, answers to bidders questions, and additional clarifications are being added to the contract documents through addendum. Most addendums can add significant contractual and cost for the contractors, yet their scope is difficult to define since they are usually verbal in nature but describe project elements that would normally be described by drawings.

The control contractor's fee restrictions result from the fact that they are bidding for work in most cases (vs. negotiating without competition). They will not get all of the projects for which they submit a bid, so some costs associated with bidding work must be supported as overhead. Thus, there can be considerable pressure to minimize the amount of effort placed into bidding a project. This bidding environment tends to work against the sales engineer developing well-planned technical solutions to design issues that are not addressed by the contract documents, especially when faced with time pressures.

- **Technical Expertise** Control contractors commonly find themselves in the position of having technical expertise that they are somewhat powerless to apply. The controls contractors are most familiar with the technical details of the proper application of their control system. In addition, many manufacturers have a staff with considerable HVAC applications engineering expertise. However, if the contract documents do not provide sufficient information to allow the controls contractor to exercise their expertise, competitive pressures to be the low bidder will usually cause the control system to be optimized for price rather than performance, quality, or ease of use. Contract documents that go beyond generic requirements to provide fundamental information and address key HVAC performance issues will allow the control contractors to apply their expertise to provide a bid for a system that truly meets the designer's intent while still being competitively priced.

- **Minimize Field Installation and Start-up Problems** Control contractors are in one of the more difficult positions during the construction and start-up phases of a project. Their submittals are customized to match the specific system configurations associated with the project and cannot be completed until the submittals for other equipment on the project are finalized. The control system installation work is also highly dependent up on the work of the other contractors since the sensors and actuators cannot be mounted until the structures on which to mount them have been constructed. Program debugging cannot begin until the systems are substantially complete and operational. In many projects, weather delays, shipping delays, and other problems cause the installation work to slip behind schedule. If the project completion date is not allowed to slip, the control contractors can find themselves caught between an inflexible project completion deadline and HVAC systems

***Knowing is Not Necessarily Doing in a Competitive Bidding Environment***

*Vague or loosely defined control system requirements in HVAC contract documents often make it difficult for those bidding the control work to do their best job if they want to be the low bidder and get the work. For instance, contract documents that say little about sensor requirements may leave the bidders with little choice other than to select the lowest priced sensor they can find that meets the letter of the documents; the required data may be provided, but the accuracy may make the sensor only marginally useful. Similarly, if system architecture issues are not addressed in the contract documents, competitive bidding pressures will force the bidders to structure the system in the least costly configuration possible. In some cases, this configuration may limit system response time, programmability, and future expansion and flexibility, all of which could be significant issues at start-up and in the future for the Owner.*

that have not been completed to the point to allow control system installation and debugging to proceed. The control contractor, like the designer, has a vested interest in minimizing installation and start-up delays in order to have adequate time to complete their installation and testing. Their benefits are similar to those realized by the Designer, including fewer warranty problems that disrupt production on other projects, improved customer relationships that can foster repeat business and better profit margins, and reduced exposure to liability.

### 2.3.3. The Owner's Requirements and Challenges

Many of the challenges faced by the design and construction team are reflections of the challenges faced by the Owner in developing the project.

- **Time and Fee Restrictions** The pressure on the Owner to complete the project and meet the timeline, budget, and market cycles can be intense because the overall success or failure of the project can be tied to these factors. While an Owner may be convinced to spend above budget in one area in order to save money in other areas, this Owner may be unwilling or even powerless to spend money outside of the original project budget. Similar constraints apply to project timelines. Technical problems with dire consequences to the design and construction team, causing them to want to extend the construction timeline or seek additional funds may pale in comparison to the consequences the Owner faces if the project does not come in on time and on budget.

The Owner wishes to foster competitive bidding with a level playing field so that the HVAC system purchased represents the best value for the money while still meeting their operational needs.

Systems that are bid as equivalent as a result of vague contract documents, but are not really equivalent on an operational basis can ultimately cost many times the first-cost savings in

wasted energy and other operational issues. On the other hand, detailed boilerplate specifications that are not customized to the specific project may provide features that the Owner does not need, increasing first cost without providing a long-term advantage.

#### *On Time, On Budget, and Too Late*

*In the late 90's, many semiconductor manufacturers entered into an expansion cycle targeted at hitting what seemed to be a skyrocketing market.*

*Unfortunately, other market and world economic forces caused a sudden downturn that occurred in a matter of months. One manufacturer was in the process of completing a 250,000 square foot expansion of their clean room facility when the downturn occurred.*

*During construction, the facilities group was baffled when management passed up some attractive energy savings opportunities in their drive to maintain schedule because implementing them might have delayed the start-up of production. The facilities group later became painfully aware of the reason behind management's drive when the facility was closed one week prior to initiating production. Even though the plant was on time and on budget, it had missed going into production during the peak of the market cycle upon which the decision to build was based. As a result, the manufacturer chose to idle the plant until some point in the future rather than run it at a loss.*

Inappropriate application of a boilerplate can result in operational problems and inefficiencies due to improper application of systems or components

- **Technical Expertise** Even though a sophisticated Owner might have considerable in-house expertise in control systems, the people in those positions seldom have time for more than a cursory oversight role for new construction due to the demands associated with operating the Owner's existing facility or facilities. A less sophisticated Owner or an Owner with only a few properties may not have in-house control expertise to dedicate to a new project until the project's operating staff comes on board. As a result, most Owners look to their design and construction team to attend to the details of developing and bringing online the control systems for their new facilities. Ideally, much of the facility-specific knowledge will be transferred to the Owner's staff during the training that occurs as a part of the start-up process. Contract documents that provide a clear basis for the control system design, supplemented by a good set of control drawings are an important part of the knowledge base that will be provided to the Owner for the life of the building. These documents will be the foundation upon which much of the operating staff's technical expertise for the building is developed. Thus, the benefits of a well-developed control design accrue to the Owner directly via the construction documents and indirectly via the control submittals that evolve out of these documents.
- **Minimize Field Installation and Start-up Problems** More than anyone, the Owner has a vested interest in having a project with a minimal number of installation and start-up problems. Problems of this type can often lead to unanticipated and unavoidable delays in completion of the facility. These delays can ripple into problems gaining the necessary occupancy permits to be able to move in tenants, or delays in production or other beneficial use of the facility, all of which can have an adverse impact on the Owner's financial plan. It is not unusual for start-up and installation problems to be only partially resolved. These unresolved issues then become ongoing operational problems and inefficiencies that require expenditures from the facility's operating budget to correct or they simply plague the operators and the tenants for the life of the facility. The benefits that accrue to the Owner from a control system design process that minimizes installation and start-up problems include fewer warranty and ongoing operational problems and improved customer relationships with tenants, which can translate into long-term leases and better rates. For production facilities, minimizing installation and start-up problems causes fewer disruptions to the production process, which results in better profitability. In both types of facilities, minimizing these problems reduces the Owner's exposure to litigation, both in defending themselves from disgruntled tenants seeking damages as well as in seeking restitution from errant designers and contractors.

## 2.4. Tying it Together

As can be seen from the preceding section, the designer, contractor, and owner have interrelated requirements and challenges associated with a project's control system. All parties have interwoven time and financial constraints under which they all must operate. The owner initiates the project to meet some specific need, often with specific technical requirements that must be met in order to be successful. Often, these technical requirements have evolved out of operating experience on other projects. The designer must understand these needs and translate them into mechanical systems that, if properly controlled, can meet them. The contractor must interpret and implement the designer's control requirements per the design intent, thus satisfying the operational needs set out at the start of the project by the Owner. Obviously, all parties benefit from a process that provides a smooth installation and problem free start-up.

Designers can take a significant step towards ensuring that their control system needs are met by incorporating certain key elements into the control system design either by including them directly on their contract documents or by requiring that they be furnished as a part of the control system submittal package (and then verifying that they are in fact provided and well executed). These components include:

- 1 **System Diagram and Sequence of Operation** A System Diagram is a schematic drawing of the arrangement of the entire system to be controlled including all interacting components. The location of all control system inputs and outputs associated with the HVAC system should be included on this diagram. In a narrative format, the sequence of operation describes the required HVAC control process in detail including all operational and interlock requirements.
- 2 **Benefits of** a Points List Each physical point on the project as well as key virtual points should be identified on a points list. The list should include important parameters such as sensor accuracy requirements, alarm limits, and trending requirements.
- 3 **Specifications** The performance and installation requirements for the sensors, actuators, final control elements, controllers, workstations and other components that comprise the control system are detailed in the specifications. Control damper and control valve schedules are an important component of these specifications.
- 4 **Floor Plans** The location of the input and output points as well as key components like control panels, operator workstations, major cable and conduit routes, and sources of power are shown on control system floor plans.
- 5 **Standard Details** Typical installation requirements for the control system elements are provided in standard details. These details can illustrate the general design intent for the system, provide a consistent basis for estimating the control price, provide the basis for the system-specific control system design development by the control contractor, and provide guidance for the other trades involved on the project who must coordinate with the control contractor.

The specification, system diagram, and operating sequence will exist in some form on just about all projects. Other elements, such as the point list, floor plans, and installation details may not be part of the normal scope of design services and may not even show up on the contractor's submittals. However, once some experience is gained, these components are surprisingly easy to generate, especially in an office that utilizes a CAD package and word processing to automate tasks. As a result, some designers are electing to include them with their design package while others are including language to delegate them to the control contractor, thus ensuring that they are attended to. These elements generate rewards through improved communication of the design intent, better bidding, fewer start-up and operational problems, which will more than pay for any added costs that may be incurred. Return on investment is also realized through improved client relationships, improved fee structures, and reductions in the often non-billable time associated with resolving disputes and handling field problems during the construction process and warranty year. The following sections will discuss each of the six components of the control system design process listed above in greater detail.

## 2.4.1. System Diagram and Sequence of Operation

Successful HVAC designs hinge on the smooth, integrated interaction between the system's components and the loads served. It is not just an air handling unit; it is an air handling system made up of an air handling unit, intake system, distribution system, terminal equipment, return system, relief, and exhaust system. It is critical that the control system

design reflect this systems-based perspective. It is this systems perspective that guides creation of the system diagram and the detailed sequence of operation.

The system diagram is a drawing that shows the entire system under consideration in schematic format, not just portions of the system. This method allows the user to see the entire process and visualize the potential interactions without having to flip between multiple documents. A detailed system sequence of operation or system narrative goes hand in hand with the system diagram in documenting the overall operation of the system. Many times, the sequence provided on the contract drawings and duplicated in the specification provides a good overview of how the system is intended to perform, but fails to address critical details which can make or break the success of the installed system. Well-documented system drawings also provide a useful field reference for the commissioning and operations personnel. More information and examples of the systems perspective is provided in the Functional Testing Guide for Air Handling Systems (Functional Testing Guide) in *Chapter 2: Functional Testing Basics*.

Most designers will find that the schematics and operating sequences typically included on their construction documents can be readily adapted to reflect the system concept, often with little effort and a great deal of benefit for an improved design process and improved installations. Often, the difficult part of this transition to the system concept is learning to write out the detailed operating narrative. This detailed narrative is just a written statement of what the designer should already know: the details of how they expect the system to function. Furthermore, the initial development effort can often be amortized over subsequent projects since many of the operating requirements for HVAC systems do not vary from project to project. This allows a designer to develop standard sequences for typical system configurations that can then be adjusted as necessary to the specific requirements of a project.

In addition to the ongoing usefulness of a well-written sequence of operation to the building operators, the sequence is essential for a smooth commissioning process. The commissioning provider must test and evaluate the system sequence based on how well it meets this detailed sequence.

Similar considerations apply to the system diagram. For most design firms, a schematic rendering of their standard systems will not vary much from project to project because the schematic arrangement is fairly independent of building geometry. This means that a design firm can develop standard schematics for the systems configurations that they use repeatedly and then tailor these standards to the needs of specific projects.

The current technology automated office environment makes all of this easy to accomplish using standard word processing and computer automated design and drafting techniques. Developing a project's system configurations and operating sequences from existing standards does not remove the need for technical assessment and expertise to adapt the standards to the specific needs of a project. It does minimize the amount of time that must be spent in this process by avoiding "reinventing the wheel".

### ***No Diagram or Narrative? No Drafters***

*Some consulting firms have found that the system diagram and narrative sequence of operations are such an integral part of a successful design, that they are required as the starting point for any new project. Before a project engineer can request drafters and designers for a project, they must have developed a system schematic, a fairly detailed narrative describing how the system should work, and a rough estimate of the heating and cooling loads. If this process is well-executed, a significant portion of the engineering required to make the project successful is complete or will fall out of the information developed. Once experience is gained, the technique can yield preliminary equipment selections and motor loads within 10-15% of final values, parameters for estimating costs, and parameters for estimating equipment room, mechanical chase, and ceiling space requirements. In addition to providing a firm basis for design, this type of information can be used to coordinate and negotiate with the other project team members from a foundation based on technical information, not rules of thumb.*

## 2.4.2. Point List

Both the narrative sequence and the system diagram provide a basis for developing the points list. Some designers incorporate the point list into the narrative sequence, while others provide it as a table in the specifications or contract drawings or by showing the points on the system schematics. Regardless of where the point list is located, it is a good idea to show the points in the proper location on the system diagram to guide the contractors during construction.

The point list should include all physical points on the project, including hardwired interlocks. It is also a good idea to include required virtual points such as calculated flows or energy consumption. Other virtual points, such as set points and tuning parameters can also be included, but these points can usually be accommodated with less effort by the designers through a specification reference or a general note attached to the point list.

While some commissioning and O&M-related points may not directly affect the ability of the control system to function, they provide a means to ensure that the system continues to perform as intended by allowing key performance parameters to be monitored, trended and alarmed. When coupled with an ongoing commissioning plan and good training for the operating staff, monitoring points enable the design intent and design efficiency of the HVAC systems to persist over the life of the facility.

### ***Physical Points and Virtual Points:***

*Computer-based control systems employ two classes of points: physical points and virtual points. Physical points exist as hardware devices, typically sensors or actuators, and are wired to the controller I/O interface. These points are the direct physical interface between the control system and the operating environment that allows the control program to execute the intended functions. They also provide important operating information for diagnostics and troubleshooting. In contrast, virtual points exist in the controller's memory and are used to store set points, counter and timer values, perform calculations, and act as logic flags. While they may represent physical quantities such as a flow rate calculated based on the differential pressure signal from a pitot tube, or a Btu consumption calculated from a flow rate and a temperature difference, there is not an actual piece of hardware (other than a location on a memory chip) associated with them. Not all virtual points are important from a design and operating perspective. Calculations that provide information about the system or variables like set points that allow the operators to manipulate the system typically are quite useful. Whether to keep memory locations used to hold timer counts or as logic flags to allow the program to properly execute can be left to the discretion of the programmer. What is important is that the designer take steps to ensure that the details associated with them are a part of the turn-over package provided to the Owner once the system is commissioned and functioning properly.*

### 2.4.2.1. Benefits of a Points List

A point list can provide a great deal of information regarding the requirements for the control system. Detailed specifications of control and monitoring points can be beneficial to both designers and controls contractors in the following ways:

- Without a points list, the determination of points is left to the contractor's interpretation of the contract documents. Often points are left out that are not necessary to execute the sequence but are useful for future sequence modifications, building control loop tuning, energy consumption analysis, and O&M troubleshooting. Adding the points later can be difficult and expensive.
- By clearly stating the minimum point requirements for the project, the designer can ensure a "level playing field" for all control system bidders.
- Requiring specific points enables the bidders to more easily obtain pricing from electrical contractors and equipment suppliers.
- The point list can be used to tie together information about the point location and function on the system diagram with information about its physical location in the building. This can be especially helpful if the points are not shown on a floor plan.<sup>1</sup>
- The point list provides a place to clarify the requirements for sensor accuracy, sensor configuration, and any other special requirements.
- The points list reveals requirements of the control system architecture. The point density required in a particular location may determine the controller network configuration and the I/O requirements for the controller.
- The points list can be developed early in design to provide a starting point for the control system budget.

### 2.4.2.2. Typical Components

In addition to listing the minimum points requirement for the project, the point list is a convenient way to specify the requirements associated with each point, such as sensor type, accuracy, and point name. An example point list is shown in Figure 2.1. The spreadsheet used to create this figure is also provided as a starting point for developing your own point list. Providing a useful points list is critical, but there are many ways to go about doing it. Some may feel that the attached example contains too much detail, the detail should be located elsewhere, or that the contractor should provide some of the information.

The following items are suggestions for consideration when developing your point list format.

- **Point Name and Symbol** The point name provides a consistent way to reference the point in the contract documents and correspondence. It may also be convenient to add a suffix indicating if the point is part of the base bid or an alternate where appropriate.<sup>2</sup> (Other point naming convention considerations are discussed in [Section 3.6.1.](#)) Some designers find it convenient to combine the point name with a drawing

<sup>1</sup> For example, the point list might clarify that the sensor shown on the system diagram at the discharge of a cooling coil with face and bypass dampers must be installed in a manner that ensures it will see only cooling coil discharge air, not the mix of cooling coil discharge and bypass air, thus ensuring the functionality of the dehumidification sequence.

<sup>2</sup> The suffix would only be used during the bidding cycle and then dropped when the system was installed and programmed.

symbol for different point types and use this information to designate the point location on the system schematics and floor plans.<sup>3</sup> (See Figure 2.9 for an example of this.) Project personnel will quickly learn to interpret these codes and will appreciate the utility they bring when reading the control drawings.

- **Applicable Details** Applicable details point the contractor or installer to drawings that further describe the point installation. A column to indicate drawing details has not been shown on the example points lists due to space constraints but is included in the template.
- **System and Service** The full name of the point and the system that it corresponds to. For many systems, this can become the point descriptor.
- **Sensor Type and Accuracy** A minimum level of accuracy should be specified. Requirements for sensor type and accuracy are presented by application in [Section 3.3 Sensor Accuracy](#).
- **Limit and Warning Alarm Requirements** See Section [3.6.4 Programmable Alarms](#) for details about selecting alarms.
- **Trending Requirements** See Section [3.6.6 Point Trending](#) for more information on trending during the commissioning process and during normal operations.
- **Bid Level** Section [3.2 Point Selection](#) can assist designers in selecting points to include as a base bid or alternative bid level. A column to indicate bid level has not been shown on the example points lists due to space constraints but is included in the template.
- **Notes** The notes column indicates details that will help the project personnel understand the purpose of the design requirements.

Figure 2.1 is an example of a typical point list where the designer specified the project point requirements in detail. Alternatively, the designer may specify only the points required and refer the contractor to the specification for some of the requirements. In this case, the designer may require that the control contractor provide a detailed point list as a part of the submittal process.

Link to Detailed Points  
List Spreadsheet

*Link to a detailed points list (Excel spreadsheet). Save this spreadsheet to use as a starting point for point lists on your projects.*

<sup>3</sup> AutoCAD® blocks coupled with visible and hidden attributes can be used to automate this process during the development of design drawings. The point blocks can be inserted where appropriate on the floor plans or system schematics and the attributes defining the point list information entered as a part of the insertion process. Then a LISP routine can be used to scan the drawings, extract the point information from the point block attributes and generate the point list. A similar approach can be used to automatically generate valve and damper schedules.

AHU01 DDC System Point List: Typical Single Duct, Constant Volume, Single Zone, 100% OSA																	
Point Name	System and Service	Sensor/Interface Device <sup>6</sup>		Features												Notes	
				Alarms		Warning		Samples <sup>1</sup>	Trending								
		Type	Accuracy	Limit		Hi	Lo		Hi	Lo	Time <sup>2</sup>	Local <sup>3</sup>	Archive <sup>3</sup>	Time <sup>2</sup>	Local <sup>3</sup>		Archive <sup>3</sup>
Analog Inputs																	
AHlPhLAT	AHU 01 Preheat Coil Leaving Air Temp	Flexible Averaging RTD w/ transmitter	+/-1.5°F	None	40°F	Note 14	50°F	15	1 min	X	X	4 min	X	X			
AHlCCLAT	AHU 01 Cooling Coil Leaving Air Temp	Flexible Averaging RTD w/ transmitter	+/-1.5°F	Note 15	50°F	Note 15	53°F	15	1 min	X	X	4 min	X	X			
AHlZn01T	AHU 01 Zone 1 Space Temp	Thermistor	+/-1.0°F	85°F	60°F	Note 11	Note 11	15	1 min	X	X	4 min	X	X			
AHlPhLWT	AHU 01 Preheat Coil Leaving Water Temp	Insertion RTD with transmitter	+/-1.0°F	None	40°F	Note 12	45°F	15	1 min	X	X	4 min	X	X			
AHlPhVfb	AHU 01 Preheat Coil Valve Position Feedback	Analog position transmitter	+/-2% of stroke	None	None	None	None	15	1 min	X	X	4 min	X	X	Note 24		
AHlCCVfb	AHU 01 Cooling Coil Valve Position Feedback	Analog position transmitter	+/-2% of stroke	None	None	None	None	15	1 min	X	X	4 min	X	X	Note 24		
Analog Outputs																	
AHlPhVlv	AHU 01 Preheat Valve Command	Electronic to pneumatic converter	+/-1.0%FS	N/A	N/A	N/A	N/A	15	1 min	X	X	4 min	X				
AHlCCVlv	AHU 01 Cooling Coil Command	Electronic to pneumatic converter	+/-1.0%FS	N/A	N/A	N/A	N/A	15	1 min	X	X	4 min	X				
Digital Inputs																	
AHlFiltr	AHU 01 Filter status	Photohelic indicator and switch	N/A	Closed	None	None	None	2	COV	X	X	COV	X	X	Note 8		
PhP1POO	AHU 01 Preheat Coil Pump 01 Proof of Operation	Current switch	N/A	Note 13	None	None	None	15	COV	X	X	COV	X		Note 7		
AHlPOO	AHU 01 Supply Fan Proof of Operation	Current switch	N/A	Note 13	None	None	None	15	COV	X	X	COV	X		Note 7		
EF1POO	Exhaust Fan 01 Proof of Operation	Current switch	N/A	Note 13	None	None	None	15	COV	X	X	COV	X		Note 7		
AHlSSwSt	AHU1 Selector Switch Status	Auxiliary contact	N/A	Note 19	None	None	None	2	COV	X	X	COV	X		Note 20		
AHlZnOr	AHU 01 Unoccupied Cycle Manual Override	Note 22	N/A	None	None	None	None	15	COV	X	X	COV	X	X	Note 23		
Digital Outputs																	
AHlOADpr	AHU 01 Outdoor Air Damper Command	Electro-pneumatic switch	N/A	Note 16	None	None	None	15	COV	X	X	COV	X				
PhP1SS	AHU 01 Preheat Coil Pump 01 Start/Stop Command	Interface relay, horse power rated contact	N/A	Note 13	None	None	None	15	COV	X	X	COV	X				
AHlSFSS	AHU 01 Supply Fan Start/Stop Command	Interface relay	N/A	Note 13	None	None	None	15	COV	X	X	COV	X				
EF1SS	Exhaust Fan 01 Start/Stop Command	Interface relay, horse power rated contact	N/A	Note 13	None	None	None	15	COV	X	X	COV	X		Note 9		
Virtual Points																	
AHlHrs	AHU 01 Accumulated Hours of Operation	Calculation based on proof of operation	N/A	None	None	1,000 hr.	None	None	None	None	None	None	None	None	Note 10		
EF1Hrs	EF 01 Accumulated Hours of Operation	Calculation based on proof of operation	N/A	None	None	1,000 hr.	None	None	None	None	None	None	None	None	Note 10		
PhP1Hrs	Preheat Coil Pump 01 Accumulated Hrs Operation	Calculation based on proof of operation	N/A	None	None	1,000 hr.	None	None	None	None	None	None	None	None	Note 10		
Hard Wired Points																	
AHlFrz	AHU 01 Low Temp Limit (Freezestat)	Manual reset freezestat	+/-1.5°F	None	38°F	None	None	None	None	None	None	None	None	None	Manual reset		
AHlFire	AHU 01 Fire Alarm Shut Down Relay	Relay by fire alarm contractor	N/A	Open	None	None	None	None	None	None	None	None	None	None	Note 18		
AHlSmk	AHU 01 Supply Smoke Detector	Detector by fire alarm contractor	N/A	Note 17	None	None	None	None	None	None	None	None	None	None	Note 18		
EF1Fire	AHU 01 Fire Alarm Shut Down Relay	Relay by fire alarm contractor	N/A	Open	None	None	None	None	None	None	None	None	None	None	Note 18		
AHlMASP	AHU 01 Low Mixed Air Plenum Static Pressure	Manual reset pressure switch	+/-0.1 in. w.c.	None	-2.0 in. w.c.	None	None	None	None	None	None	None	None	None	Manual reset		
AHlOALSw	AHU 01 Outdoor Air Damper Limit Switch	Lever action type limit switch	N/A	Open	None	None	None	None	None	None	None	None	None	None	Note 21		

Figure 2.1 Detailed Points List



Table 2.1 lists point types that are commonly found on air handling systems. Each of these categories of points should be included in the points list.

**Table 2.1 Common Air Handling System Points Specified in Contract Documents**

Analog Inputs	Digital Inputs	Analog Outputs	Digital Outputs	Virtual Points
System discharge temperature	Fan proof of operation	Economizer damper command	Fan Start/Stop	Set points
Mixed air temperature	Filter status	Relief damper command	Drive Enable/Disable <sup>1</sup>	Calculated flow rates
Coil leaving temperature	Humidifier proof of operation	Face and bypass damper command	Humidifier shut down	kWh consumption
Zone temperature	Preheat coil pump proof of operation	Hot water valve command	Preheat coil pump command	PID constants
Zone humidity	Selector switch status	Chilled water valve command		
Duct system pressures	Override switch status	Humidifier valve command		
Building and zone pressures	Low temperature limit status <sup>2</sup>	Drive speed command		
Outdoor air conditions	Mixed air plenum static safety status <sup>2</sup>	Inlet vane command		
Return air CO <sub>2</sub> level	Discharge static safety status <sup>2</sup>			
Valve and damper actuator positions	Return static safety status <sup>2</sup>			
Direct flow rate measurement	Power status <sup>3</sup>		Power status <sup>3</sup>	
Terminal zone flow rates	Fire alarm status			

**Note 1** There is a subtle difference between a start/stop point and an enable/disable point. A start/stop point will directly control a piece of equipment; when the command is sent, the equipment will immediately respond. In contrast, an enable/disable point is a permissive command that allows some other control system to start or stop the equipment based on its internal parameters. A Start/Stop command might be used to cycle a single speed fan or pump controlled by a starter. An Enable/Disable command might be used to cycle a fan or pump that are controlled by a VFD where the start sequence programmed into the drive might include a DC injection braking command prior to the start command.

**Note 2** The actual safety control should be hardwired into the common side of the related interlock circuit. To save point capacity, a general safety status point can be provided instead of specific points for each safety device.

**Note 3** Power status is a relay contact wired to the same power source as the control and fan system. The point triggers a power recovery restart routine to safely restart the system after a power failure. Many controllers now have this feature built into them so they can accomplish the function without using any of their I/O.

## 2.4.3. Specifications

The technical specifications associated with the control system are an important part of the overall controls design because they contain many of the technical details that are critical to success. The function and content of the control specification are just as important as other mechanical sections. For instance, most piping specifications contain detailed descriptions of the valves, pumps, chillers, piping specialties, and other components used to build up the piping system. Designers would not put a project out to bid without this important information for the piping system, but this kind of detailed information is not typically included for control system. The lack of a detailed control system technical specification can lead to difficulty meeting the owner's design intent.

Control technology has changed so quickly in the last 15 to 20 years that it got ahead of the standard technical specifications used by most engineering firms. While there have also been technological changes in mechanical systems, they have generally been more easily accommodated by making modifications to the fairly detailed mechanical specifications that already exist. For instance, the application of variable speed drives to variable flow fan and pumping systems required that either the mechanical or electrical designer develop a specification paragraph for the drive itself and perhaps make adjustments to the motor, fan, and pump specifications that they already had in place. In contrast, the evolution of control systems from networks made up of pneumatic, electric, and electronic components to computer based DDC systems required modifications to nearly every paragraph of a typical control specification section and additional requirements. Not only did the technology change, the materials and methods required to implement it and the language required to describe it changed. As a result, the responsibility for implementing the details of the controls design is often delegated to the controls contractors, either directly by performance specifications or indirectly by a simple lack of detail in the contract documents. The contract language for control systems is often so vague that it can be interpreted liberally at the expense of quality and performance. With dedication to writing detailed control system technical specifications and then enforcing them, designers can successfully create a level playing field for quality controls installations.

Designers that are uncomfortable with writing specifications for the latest technology in DDC control systems should consider the following points:

- **Most of the HVAC processes that are controlled by current technology DDC systems were successfully implemented with the control technology that existed prior to the advent of DDC.** Successfully defining the control system design revolves around HVAC and mechanical parameters, regardless of the control technology. Thus, if designers can learn to communicate these HVAC needs clearly, significant improvements in performance will be realized regardless of whether or not the designer is fully fluent in networking, programming, and other DDC control implementation strategies.

For example, the system designer may not know whether Ethernet, ARC Net, or a proprietary networking strategy is the best way to achieve their design intent. But they should know that for their system to perform as required, the control system would need to monitor certain points within a certain accuracy tolerance and distribute the information within a certain time frame. By conveying these important design details to the contractor through the contract documents, the designer helps ensure a good control installation regardless of their level of familiarity with the details of DDC controls design or the specifics of a particular manufacturer's system.

- **Most of the new control technologies come back to the same physical principles that apply to the older technologies.** Thus, those who are well-versed

in HVAC processes can understand any new control technologies to the extent necessary to develop a good control design. All control and sensor technologies come back to fundamental concepts. For example, chilled mirror technology for measuring dew point functions by cooling the mirror to the point where dew is formed and detecting this point. The details surrounding exactly how this process is achieved are not necessary to specify the sensor type for a particular application.

The following sections will give designers guidance in creating a level of detail in the control system specifications that will help ensure that quality control systems are implemented.

- **Scope of Work**
- **Component Specifications**
- **Operator Work Stations**
- **Installation Requirements**

### 2.4.3.1. Scope of Work

In addition to a general statement of work for the control system scope, some designers find it desirable to include more specific references to the applicable components of the overall scope. These references can be a particularly useful guide since the control work often touches the work of many other trades and sections of the specifications. General areas of control system work often include:

- **Components** of the control system such as controllers, workstations, sensors, actuators, and auxiliary control panels and equipment.
- **Conduit and wiring** required for the control system inputs, outputs, and network communications. Power wiring for the controllers and actuators and terminal units should also be included if it is not covered by other sections.
- **Control air piping** including a source of supply if pneumatic actuation is used and an existing control air system is not available.
- **Equipment interfaced to the control system** including chillers, boilers and variable speed drives.

Coordination with other specification divisions and trades that must interface with the control system is essential. This coordination must occur among:

- The commissioning provider, who will be involved in the check-out of the equipment and control system.
- The mechanical trades that mount the sensing and calibration wells, pressure sensing ports, control valves, flow meters, and other accessory equipment required by the control system.
- The sheet metal trades who often install dampers.
- The electrical trades that typically furnish and wire the electrical starters, which are interfaced to the control system. In addition, the control contractor often furnishes safety switches that are installed by the electrical trades.
- Engineering and technical support as required to develop and supervise the shop drawings, database, and programming.

Because the control work touches the work of many trades, it is desirable to insert language giving specific instruction regarding the interface between that trade and the control contractor. For instance, the piping section in the specification may need to

layout specific requirements for the installation of flow meters, control valves and other control equipment that is furnished by the control contractor. For example, some flow meters require special jigs to ensure accurate alignment of the sensing heads when they are welded to the pipe, and these requirements should be included in the specifications.

### 2.4.3.2. Component Specifications

Many designers would argue that they simply do not have the fee, time, or expertise necessary to develop detailed component specifications for the control system. Much of the control system component quality control will be achieved via the specification language. Failure to expend effort in component specification will often compromise the quality of the control system and impede the ability of the overall design to achieve its design intent.

#### Sensors and Actuators

A control system is only as good as the sensors that provide information to it and the actuators that allow it to interface with the equipment. Thus, the specifications for these components are critical. The controller Input/Output (I/O) circuit boards provide the interface between the DDC processors and the sensing and actuating system. While it is not necessary to understand or specify the details of how this interface works, it may be desirable to include language in the spec that covers some features in this area. Topics to consider include:

- **I/O Modularity** Some controllers use a modular I/O approach to allow them to be configured to the exact requirements of a project by selecting the correct assortment of input and output modules. Other controllers utilize circuit boards with a fixed number of points with specific capabilities.<sup>4</sup> These features may be important to an Owner or designer in the context of future expansion capability, adaptability to HVAC system modifications, or maintenance requirements.
- **Processor Modularity** Some controllers have all of their electronics including the processor and I/O hardware mounted on the same circuit board. Others have modules for each of the major functions. The single circuit board approach tends to hold first costs down, but can represent a significant maintenance cost in terms of materials, labor and downtime since the entire controller will be unavailable and must be replaced if any single component fails.
- **Override Capability** One important feature that may only be available on certain controllers in a particular manufacturer's product line is the ability to manually override an output. If the manual override is a standard feature on the output circuit boards, it often includes the ability to monitor the status of the override switch. Alarms can then be generated if a controller is taken out of the auto mode. The operator can also verify that each output is actually in auto. This feature is useful during start-up and commissioning and in emergencies.<sup>5</sup>

Sensor specifications should address every type of input that is required on the project from the analog temperature and pressure sensors to the digital current sensors and filter switches. Some sensor types may involve multiple specification paragraphs to define the

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<sup>4</sup> A variation on the latter design approach are controllers with fixed point counts that can be adapted to a variety of input and output signals via termination techniques and software parameters that are set by the installing technician. Some are so flexible that the points can serve as inputs or outputs.

<sup>5</sup> Some Facilities Engineering groups consider this feature to be important enough that they make it a mandatory part of their system requirements. If a manufacturer does not offer this feature as a standard built-in component on their circuit boards, then they must provide the function in an auxiliary field panel.

accuracy or sensing element requirements for different applications. For instance, some projects may require two different immersion temperature sensor specifications, one for hot water applications where larger operating spans and lower accuracy is acceptable, and a second paragraph for chilled water applications where small spans and high accuracy may be necessary to achieve the desired degree of precision. Similarly, a duct temperature sensor specification may require several sub-paragraphs dedicated to single point elements, rigid averaging elements and flexible averaging elements.

Actuator specifications also need to be tailored to each project. In many instances, the actuator specifications will be included with the specifications for final control elements like dampers or control valves. Regardless of where they occur, the specifications should address power source (pneumatic, ac or dc electric), actuating force, actuating speed, precision, position feedback requirements, shut-off requirements, and auxiliary requirements such as positioning relays and limit switches. Where DDC controllers will drive pneumatic actuators, specifications regarding the electronic to pneumatic interface devices should also be included. Important items to address might include the required output span, requirements for a gauge to indicate output pressure, and the ability to manually override the output.

Additional information regarding sensors and actuators can be found in *Chapter 3: Selection and Installation of Control and Monitoring Points*.

## Final Control Elements

The most common final control elements in current technology HVAC systems are control valves, control dampers, and variable speed drives. Each of these components require special attention in the specification language. The control work for these components must coordinate with the work of other trades and other sections of the specifications since the elements might be:

- Furnished and controlled under the control specification section but installed under other sections or divisions of the specification.
- Furnished and installed under other sections or divisions of the specification and controlled under the control section.
- Furnished, installed and controlled under the control section of the specification.

The multi-disciplinary aspects of these elements may also require special attention to coordination during design since the design work for different sections or divisions of the specification is often done by different design firms that specialize in a particular area.

### Control Valves

Regardless of who furnishes the control valves for a project, important parameters must be addressed in specific terms in order for the design to be successful. These parameters include:

- Materials of construction
- Temperature and pressure ratings
- Actuator power source, failure mode upon loss of power, and operating speed
- Maximum shut-off differential pressure requirements
- Sizing

Ideally, the designer should address all of these parameters directly in the design documents, but there are other options. Again, what matters is that the details be addressed by someone who is held responsible for the outcome. A valve schedule with a line for each valve on the project and a column for each parameter to be specified is an ideal way to address the details of valve sizing and selection. This could be included on the drawings or as a part of the specifications. Figure 2.2 is an example of a typical valve schedule where the designer specified the valve design requirements in detail. Figure 2.3 is a similar schedule but has been used by the designer to specify the critical performance criteria, leaving final selection and development of the details of the schedule to the control contractor. The link below will take you to copies of these examples as well as a blank version of the spreadsheet which will calculate valve Cvs based on standard ASHRAE equations if you provide the flow and pressure drop targets associated with your design.

[Link to Valve Schedule Spreadsheet](#)

*This spreadsheet is a blank version of Figure 2.2 and Figure 2.3. You can use this spreadsheet as a starting point for valve schedules on your projects.*

Control Valve Schedule - Engineering Data							
Valve Number	Unit or System Served	Water Service		Steam Service			
		Gallons per Minute	Close Off ft.w.c. (Note 1)	Pounds per Hour	Inlet pressure psig	Super heat °F	Outlet Pressure psig
V-1	AHU-1 Preheat Coil	81	60				
V-2	AHU-1 Humidifier Control			409	12	0	0
V-3	AHU-1 Humidifier Shut-down			409	12	0	12
V-4	AHU-1 Chilled Water	45	58	N/A	N/A	N/A	N/A

Control Valve Schedule - Valve Data					Control Valve Schedule - Actuator Data						
Control Valve Data					Actuator Data						Comments
Target $\Delta P$ , ft.w.c. (Notes 2,3)	Target $C_v$ Note 7	Valve Size, inches	Valve Type	Manufacturer/Model (Note 4)	Action	Failure Position (Note 5)	Type	Power	Range (Note 6)	Manufacturer/Model (Note 4)	
10	39	2"	Globe	Siemens 284-03179	N.O.	Open	Pneu.	TC Air	3-8 psi	See valve info.	Positioner, high temp.
	10	Note 8	Globe	Note 8	N.C.	Closed	Pneu.	TC Air	8-13 psi	See valve info.	
Minimize	Line size	2"	Globe	Siemens 278-03143	N.C.	Closed	Pneu.	TC Air	3-8 psi	See valve info.	High temp, stainless trim
10	22		Globe	Siemens 283-03133	N.C.	Closed	Pneu.	TC Air	15-20 psi	See valve info.	Positioner

**Figure 2.2 Typical Detailed Valve Schedule**

In this example, the designer has sized and selected the valves in addition to specifying the key performance parameters integral to achieving the design intent for the project. This approach allows the designer to assert the most control of the valve selection process but also requires a higher level of expertise and a more significant time commitment during design than the approach illustrated in Figure 2.2.

Control Valve Schedule - Engineering Data							
Valve Number	Unit or System Served	Water Service		Steam Service			
		Gallons per Minute	Close Off ft.w.c. (Note 2)	Pounds per Hour	Inlet pressure psig	Super heat °F	Outlet Pressure psig
V-1	AHU-1 Preheat Coil	81	60				
V-2	AHU-1 Humidifier Control			409	12	0	0
V-3	AHU-1 Humidifier Shut-down			409	12	0	12
V-4	AHU-1 Chilled Water	45	60	N/A	N/A	N/A	N/A

Control Valve Schedule - Valve Data					Control Valve Schedule - Actuator Data						
Control Valve Data					Actuator Data						Comments
Target ΔP, ft.w.c. (Notes 3, 4)	Target C <sub>v</sub> <b>Note 8</b>	Valve Size, inches	Valve Type	Manufacturer/Model	Action	Failure Position (Note 7)	Type	Power	Range (Note 6)	Manufacturer/Model	
10	39	Note 6	Note 6	Note 6	Notes 5, 6	Open	Note 6	Note 6	Notes 5,6	Note 6	
	10	Note 6	Note 6	Note 6	Notes 5, 6	Closed	Note 6	Note 6	Notes 5,6	Note 6	
Minimize	Line size	Note 6	Note 6	Note 6	Notes 5, 6	Closed	Note 6	Note 6	Notes 5,6	Note 6	
10	22	Note 6	Note 6	Note 6	Notes 5, 6	Closed	Note 6	Note 6	Notes 5,6	Note 6	

**Figure 2.3 Typical Performance Criteria Based Valve Schedule**

In this example, the designer delegated the details of the valve sizing to the control contractor based on critical design criteria specified in the valve schedule. The flow coefficients are targets calculated by the spreadsheet based on ASHRAE sizing equations and the criteria specified by the designer. The designer could elect to simply fill the flow coefficient column with *Note 6* and let the control contractor make all the valve design decisions. However, the calculations are fairly simple, especially when automated using the spreadsheet provided. Including these criteria gives the designer more leverage to ensure that the correct valve is supplied.

Many product lines have a “hole” in the range of  $C_v$  values available. If a supplier charged with sizing the valves discovers that the  $C_v$  requested for a particular valve falls in this “hole”, they are often tempted to use the closest larger size rather than go to a competitor’s product line that has an appropriate  $C_v$ . The resulting oversized valve can lead to control problems in the long run. Including a target  $C_v$  in the designer-specified parameters helps drive home the point that the valves need to meet the performance requirements of the project, not the product capabilities of the supplier’s product line.

If time or budget precludes this depth of involvement on the designer’s part, then the decisions should be clearly delegated to the contractor and held to acceptable performance criteria. A designer might include performance specifications by specifying that:

- Materials of construction and temperature and pressure ratings be equivalent to what is specified in the piping section of the specification for a valve serving the same system.
- The actuator power source, operating speed, and failure mode be consistent with the requirements of the control sequence and the overall actuation strategy that the control contractor is using on the project. The strategy (for instance, pneumatic actuation using electric-to-pneumatic signal converters) may be specified by the designer or left to the discretion of the control contractor.
- The valve actuators have sufficient actuating force to shut off against the peak pressure on the pump curve for the pumps associated with the system plus a safety factor.
- The valves for modulating service are sized for a pressure drop that is equal to the design flow pressure drop through the load they serve  $\pm 10\%$ .
- Two-position valves are line size and selected for minimal pressure drops when wide open.

Installation requirements can often be addressed by general specification language supplemented by a standard detail. Language and details associated with installation requirements will need to be included or referenced in the specification sections and drawings for the trades installing the valves.

### **Control Dampers**

Considerations similar to those stated in the preceding section with regard to control valves also apply to control dampers. Parameters to include in the specification language are

- Materials of construction
- Blade configuration (parallel or opposed, air-foil or flat plate)
- Leakage requirements
- Torque requirements (both for actuation and to ensure that the leakage specifications are met)
- Actuator power source, failure mode upon loss of power, and operating speed
- Sizing

As was the case for control valves, the designer can address each of these issues specifically for each damper on the project via a damper schedule or some other means. No matter what the process, it is important that someone is charged with taking care of the details associated with the damper selection and sizing.

The link below will take you to a spreadsheet that you can use as a starting point for developing your own damper schedule. It includes an example of the calculations used to size the minimum outdoor air, economizer, and relief dampers as well as damper characteristic curves. However, you can also address these issues in more general terms in a manner similar to that described for control valves in Figure 2.3.



*This spreadsheet is a blank version of Figure 2.3 and Figure 2.4. Use this spreadsheet as a starting point for valve schedules on your projects.*

Control Damper Schedule - Dampers														
Damper Number	Unit or System	Nominal Size		Blade Characteristics		Damper Performance Data								
		Height (in.)	Width (in.)	Blade Orientation (Note 1)	Blade Design (Note 2)	Design Flow Rate cfm	Leakage		Sizing			Basis (Note 5)		Type (Note 6)
							Rate cfm per sq.ft. of	Pressure difference in.w.c.	Target ΔP in.w.c. (Note 3)	Target Velocity fpm	Target alpha (Note 5)			
												System	ΔP in.w.c.	
AHU1-MinOA	AHU1 Min OA	6	32	Horizontal	Flat plate, parallel	3,000	10	1.4	0.48	2,000	Note 12	Note 12	Note 12	Two Position
AHU1-OA	AHU1 OA	12	42	Horizontal	Flat plate, parallel	7,000	10	1.4	0.48	2,000	5-10	Supply	3.5	Modulating
AHU1-RA	AHU1 Return Air	12	42	Horizontal	Flat plate, parallel	7,000	10	1.4	0.48	2,000	5-10	Supply	3.5	Modulating
AHU1-RelA	AHU1 Relief Air	48	48	Horizontal	Flat plate, parallel	7,000	10	1.4	0.01	438	10-20	Max. bldg. press.	0.1	Modulating

Control Damper Schedule - Actuators								
Actuator Data								Comments
Action	Failure Position (Note 7)	Type	Power	Range (Note 8)	Quantity	Location (Facing with the air flow)	Manufacturer/ Model (Note 4)	
NC	Closed	Pneu.	Air	Note 9	1	Note 10	Note 11	
NC	Closed	Pneu.	Air	Note 9	1	Note 10	Note 11	
NC	Closed	Pneu.	Air	Note 9	1	Note 10	Note 11	
NC	Closed	Pneu.	Air	Note 9	1	Note 10	Note 11	

Figure 2.4 Typical Detailed Damper Schedule

Damper installation requirements may be slightly more complex than those associated with control valves because parameters such as blade orientation relative to the air stream, blade rotation, actuator location, actuator linkage arrangement, and multi-section reinforcement requirements should be specified. These details are especially important in mixing applications or for large, multi-section dampers. If time and budget permit, the designer can detail each mixing damper assembly to the extent necessary. But the general requirements could also be conveyed via standard details with language in the specification delegating the responsibility of detailing each damper assembly to the control contractor. Any details included in the drawings should be supplemented by specification language. As discussed for control valves, any installation detail requirements need to be included directly or by reference in the drawings and specifications governing the work of the trades that install them.

Additional information regarding control dampers can be found in the Functional Testing Guide, *Chapter 5: Economizer and Mixed Air*, Section [5.4.1.1 Damper Oversizing](#).

## Variable Speed Drives

- Variable speed drives are seldom furnished under the control section of the specification. The language required to adequately define the drive is well-developed and thus will not be discussed here. However, regardless of who furnishes the drives, the control contractor will usually need to interface to them to properly execute the control sequences. The coordination requirements associated with this interface need to be addressed clearly by the control system design. Usually, these requirements can be adequately accomplished through specification language, but a supplementary standard detail is a desirable addition to convey intent for bidding purposes. Interface requirements to be addressed include:
  - **Safety device interlock requirements** that function in all operating modes (hand and auto as well as inverter or bypass for drives equipped with bypass capabilities).
  - **DDC start-stop command interlock requirements** Should the start-stop command operate in inverter mode and bypass mode, or just inverter mode?
  - **Drive to DDC system interface technique** Should hardwired data points be provided or should a communications-based interface that allows the drive to communicate with the DDC system at a communications bus level be provided?
  - **Drive programming requirements and responsibilities** Define who sets and adjusts the programmable settings in the drive such as acceleration and deceleration times and DC injection braking settings as required to tune the drive to the control program and HVAC system.
  - **Control loop programming and parameter locations:** Will the control loop program run on the drive circuit board or in the DDC controller? Many drives can accept an input signal from a sensor, a set point signal from a control system and then can execute a PID control loop directly in their on-board microprocessors, making the drive control relatively independent of the control system. In a more traditional approach, the controlling input is wired to the DDC controller and runs the PID loop at that location. An output from the controller is then used to modulate the drive.

As with the other final control elements, any installation details need to be included directly or by reference in the drawings and specifications governing the work of the trades that install the drives.

Additional information regarding variable speed drives can be found in the Functional Testing Guide, *Chapter 12: Fans and Drives*.

## Controllers and Architecture

An entire design guide could be dedicated to the subject of DDC controllers and system architectures. A knowledgeable designer could develop extensive specifications documenting the specific requirements in this area. However, compared to not addressing the control system controller and architecture requirements at all, significant improvements can be made to control system specification language by addressing the key issues described in the following paragraphs.

### Application Specific Controllers vs. Fully Programmable Controllers

Not all DDC controllers are created equal. In addition to having varying point capacities, processing speeds, and communications speeds, the programming capabilities of different controllers can vary significantly.

Application specific controllers have many of the standard HVAC operating strategies pre-programmed into their memory. This programming simplifies the installation and start-up process because the installing contractor simply selects which algorithms need to be executed to match the specified sequence, fills in input and output names and set points, and the system is functional. This approach minimizes start-up bugs since many of the problems were worked out when the installed applications were developed and “burned” into the controller’s memory. However, the application-specific controllers can only execute the functions for which they have been preprogrammed. If the controller is applied to a customized system, this limitation can be significant. The control logic required to execute specialized functions becomes complex because it becomes necessary to “fake” the controller into

***Keeping the Inputs, Outputs, and Control Logic Together:*** The inputs and outputs associated with a control loop should be connected to the same circuit board that is running the PID loop program. This configuration avoids the problems that can occur when the control system communication bus becomes a part of the control loop. Consider the case in which a static pressure sensor wired to the DDC system is used to control a supply fan drive, and the drive uses its internal PID loop program for control based on this static pressure data. The DDC system must transmit the static pressures data to the drive via the communications network. The rate at which this data transfer occurs can vary as a function of other network activities; thus a variable time constant is introduced into the control loop, which can cause tuning problems. In addition, a communications network failure results in a control loop with no input, a potentially dangerous condition. In contrast, if the static pressure sensor was wired directly to the drive controller board (assuming the drive’s on-board PID loop was going to be used to control the drive instead of a PID loop in the DDC system), then the control loop would be immune to the effects of communications failures or network activity levels. The static pressure data could then be shared with the DDC system over the network for monitoring purposes.

performing the desired sequence. The manipulations to the existing sequences may not be obvious to an operator troubleshooting a problem at a later date. In addition, the lack of flexibility associated with an application-specific controller can limit the adaptability of the system to handle problems during start-up and future changes in a manner that is not addressed by the “canned program”. The first cost advantages and simplicity offered by application specific and lower level controllers should be carefully weighed against this loss of flexibility for handling start-up problems and future system configuration changes when project specifications are developed. Generally, this type of controller is desirable for smaller systems and terminal equipment where the requirements are standardized and unlikely to change.

Larger central systems and equipment are often best served by a fully programmable controller. When using a fully programmable controller, all program logic must be developed for the project and customized for the application.<sup>6</sup> As a result, programming costs will be higher for this type of controller. Start-up and debugging of these controllers will also tend to be more expensive than an application specific controller due to the customized nature of the program. However, these controllers offer nearly unlimited flexibility (given sufficient memory and point capacity) that can be valuable during start-up and over the life of the HVAC system.

### **Polled Communications vs. Peer-to-Peer Communications**

Controllers on a peer-to-peer network communicate interactively with each other at a equal or nearly equal level; i.e. as peers. Peer-to-peer controllers exchange information in a manner that gives each controller the ability to “talk” or “listen” to the information presented on the network by the other controllers. A network that is operates in this manner will generally will be more robust and generally faster than a polled network.

On a polled communications network, inter-controller communications are controlled by a supervisory interface. For one controller to share information with another controller on the network, the supervisory interface must first “ask” the controller with the desired data for the required information, then the supervisory interface must “tell” the controller that needs the data the information. This process will occur even if the two controllers that need to exchange the data are physically wired together. In addition, the lower level controller generally must wait for the supervisory controller to ask it for information even if this information has changed significantly. While both of these processes tend to reduce the cost of the controller, they also slow down the system and make it less responsive. The number of controllers on the lower level network can also have a significant impact on communications speed because the supervisory interface becomes a communications bottleneck when the number of controllers it must supervise is large.

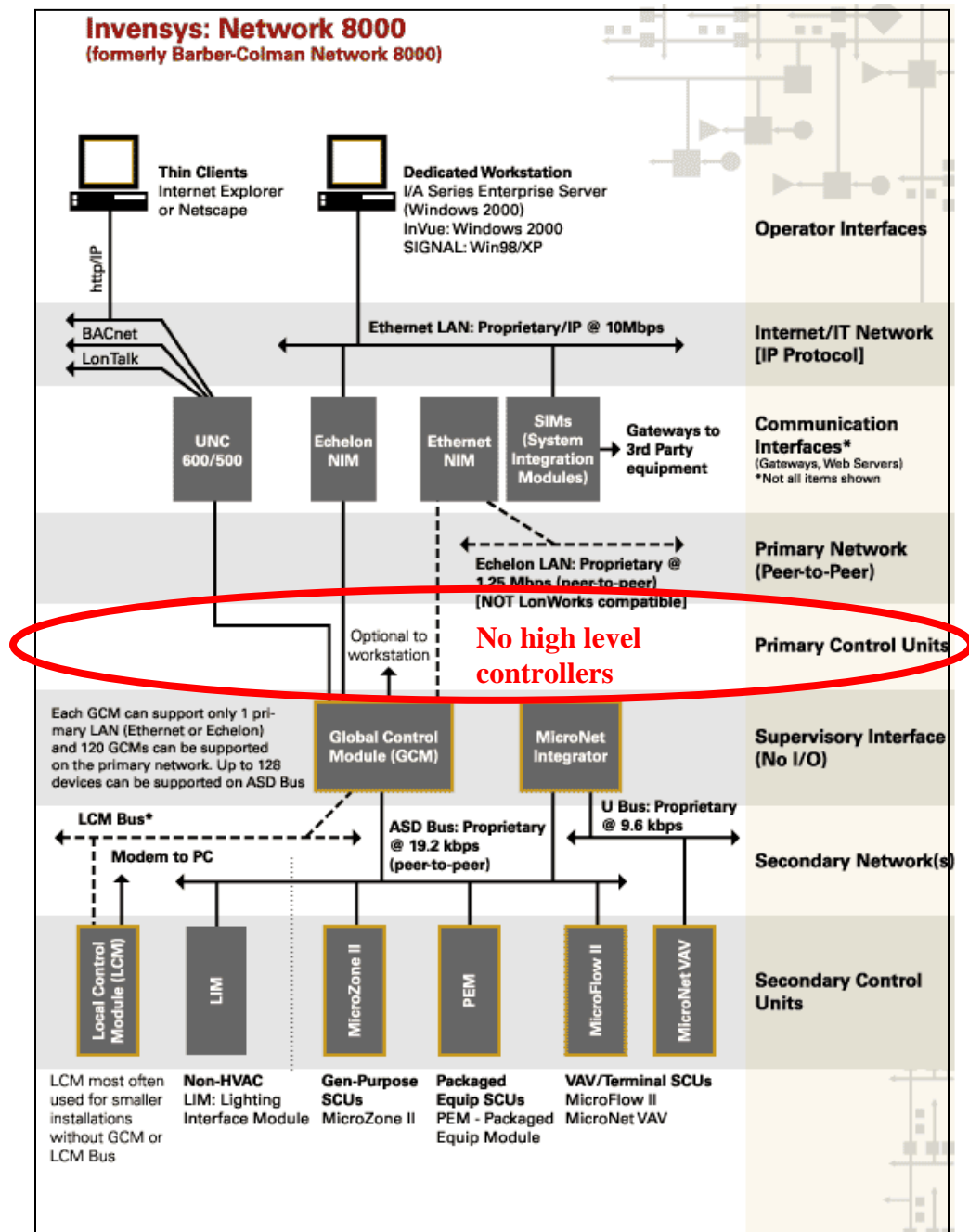
Both peer-to-peer and polled communications may have an appropriate place in any given control system. Polled communications will generally be satisfactory for controllers associated with small machinery and terminal equipment where the need for information from the network is modest. However, a polled communications strategy can become a hindrance if it is employed for larger controllers with high point densities controlling interactive machines, especially if the system needs to handle a significant amount of data for trending or monitoring. In this type of application, peer-to-peer communications will provide superior performance.

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<sup>6</sup> Copying and modifying logic from a similar project can offer some benefits in terms of reducing programming costs. Once a program is developed and debugged, it can be applied to similar systems on a current project to minimize development and start-up costs.

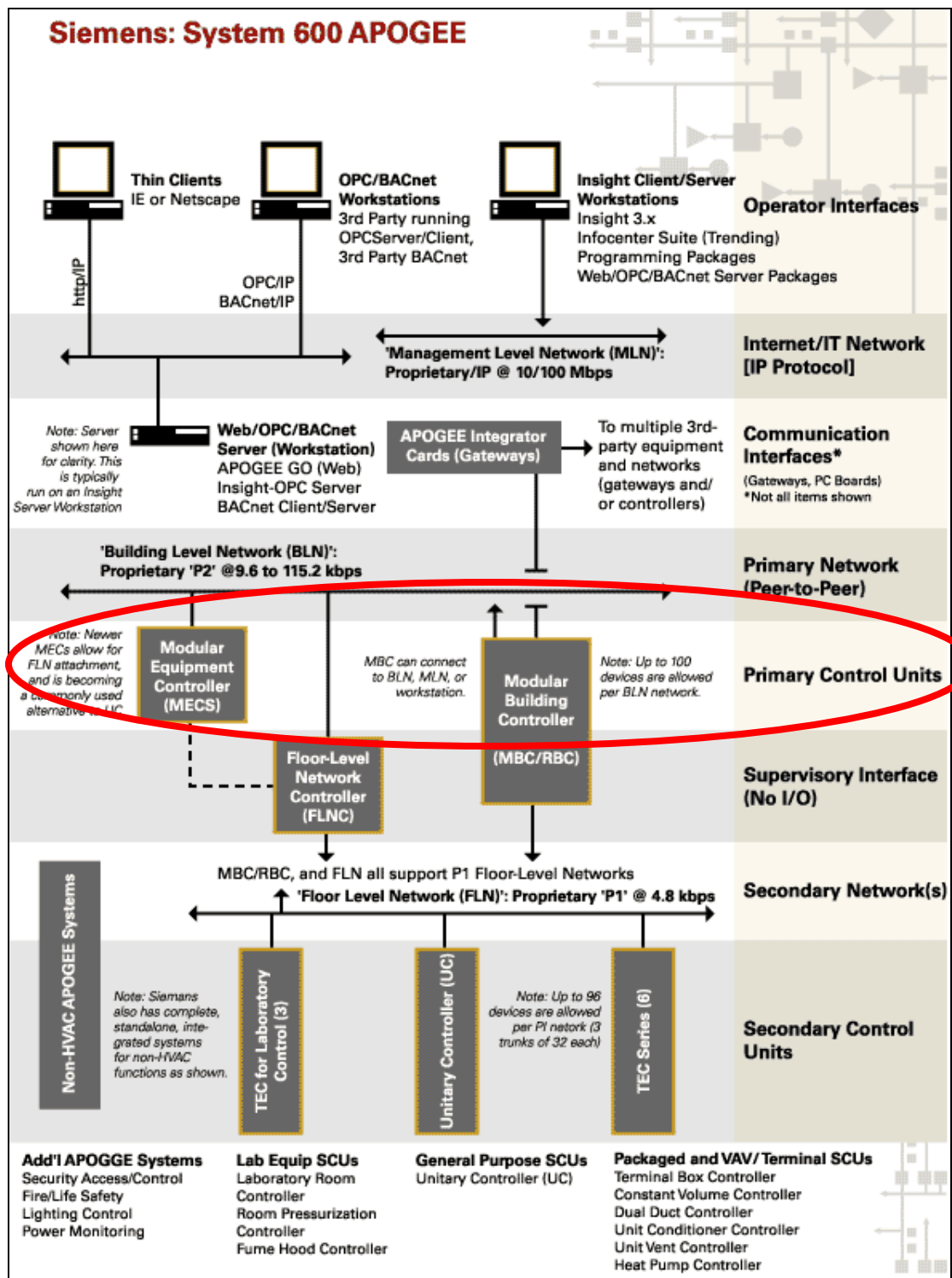
## High Level vs. Low Level Controllers

The network architectures provided by the various manufacturers generally include two levels of controllers. Not all manufacturers have systems with controllers at both the high and low levels. Figure 2.5 and Figure 2.6 illustrate this for two different systems.



**Figure 2.5 Control System Network with No High-level Controllers**

Image courtesy of the DDC Online Web Site ([www.ddc-online.org](http://www.ddc-online.org))



**Figure 2.6 Control System Network with High-level Controllers**

Image courtesy of the DDC Online Web Site

The following features distinguish high-level controllers from low-level controllers:

- **Memory** All controllers will have programmable and non-programmable memory. The non-programmable memory is used for the controller's operating system and other built-in logic that allows the controller to function and communicate. In application specific controllers, the non-programmable memory will also include the HVAC application programs for which the controller was designed. The programmable memory includes the user-generated programming as well as other data like the point data base and trends. High-level controllers tend to have significantly more memory than low-level controllers, and often have the capability to expand the base memory allocation by the addition of memory chips or cards. In most control applications, you will never have too much memory, so it is wise to specify that all controllers be provided with the maximum amount of memory available. Memory that is unused for programming purposes is available for trending, a powerful commissioning and operational tool.
- **Communications** Most low-level controllers communicate over relatively low speed, polled networks and are subject to the communications limitations associated with that strategy. High-level controllers will communicate over high speed peer-to-peer networks, making them robust and responsive.
- **Programming Capabilities** Generally, high-level controllers will be fully programmable devices with a wide range of functions available to them in their program logic set. In contrast, low-level controllers may be fully programmable. If lower level controllers are fully programmable, they may have limited logic capabilities compared to a higher level, fully programmable controller. For instance, basic math functions such as addition, subtraction, multiplication and division may be supported, but more advanced functions like powers and roots may not be supported. This may limit the usefulness of the controller even if it is fully programmable.

All of these topics are discussed in detail in two excellent resources:

An article in the May 2001 issue of Heating, Piping and Air Conditioning titled *All Controllers Are Not Created Equal - Knowledge Of The Differences Is Key To Specification* by J. Jay Santos, PE is available for download from the HPAC website at [www.hpac.com](http://www.hpac.com). This article discusses the various types of controllers and their capabilities in detail and provides guidance for the development of specifications.

- 2 The Iowa Energy Center *DDC On Line* web site at [www.DDC-online.org](http://www.DDC-online.org) presents 20 different product lines in a generic "ladder" by the classification of the device. The examples used in Figure 2.5 and Figure 2.6 are screen captures from this website.

## Interoperability

*“The ideal control system is a fully integrated network where all the components share a universally understood communications protocol and similar components from different manufacturers can be directly substituted in a plug and play environment. We used to have this in our control systems; it was called pneumatics.”*

**J. Jay Santos speaking at the 10th National Conference on Building Commissioning**

The advances in control technology brought about by the advent of DDC controls have severely limited interoperability of different control system manufacturers, as described in the preceding quote. Ultimately, DDC technologies will most likely evolve to the level of interoperability achieved by pneumatic components. Until then, there can be significant integration issues that need to be addressed if the equipment from one manufacturer is required to interface with the equipment from another manufacturer. Great strides have been made in this area in recent years through gateways and common languages, like BACnet or LonWorks networks, but true interoperability is still difficult to achieve. Large buildings or buildings located on campuses with central monitoring and control networks may want to include language in their specifications that addresses some or all of the following issues:

### **Is integration necessary and, if so, what systems should communicate and at what level?**

This is the key question, and can be as much a matter of Owner preference as a design issue. Since most buildings and the utility systems that serve them must operate as a seamless, integrated whole, a compelling argument can be made for integrating all of the various systems from an operational perspective. You may want to ask yourself the following questions:

- Should control systems from different vendors be integrated to provide a seamless picture of the site operation at the operator’s workstation?
- 2** Should the HVAC control system be integrated with the fire alarm system to enhance fire and smoke management functions and response times and to allow “smart” fire detection equipment sensitivities to be integrated with occupancy schedules?
- 3** Should the HVAC control system be integrated with the security system to allow security detection functions to be integrated with occupancy schedules?
- 4** Should the HVAC control system be integrated with other facility management systems to allow scheduling functions entered in one system to facilitate preventive maintenance and purchases?
- 5** Should the HVAC control system and other networked building management functions integrate with the facility or site Intranet to minimize communications costs and maximize the availability of system operating information?
- 6** How vulnerable does placing the HVAC control system networking function on the site Intranet make it to failures related to network problems and hacking?
- 7** Will a UL Listing be required for all integrated components associated with a fire or life safety system? If so, can the proposed integration solution provide this?
- 8** Will customized software be required to integrate multiple vendor packages into a workable system, and if so, how expensive will this be to maintain compared to ongoing revisions to the operating software of all of the systems?

- 9 Does a manufacturer's advertised interconnectability translate into interoperability, or will the installation still require significant programming efforts to achieve the desired level of integration?
- 10 Does the data transfer rate across the interface make the interface a usable tool, or is it so slow or limited that it provides little practical value?
- 11 Does the integration really lower operating and maintenance costs, or does it increase them due to the need to maintain and be familiar with the multiple vendor tools, products and equipment necessary to perform system specific programming and maintenance?
- 12 Does the Owner understand that in most cases, "plug and play" integration does not exist in current technology even though the operator interface may make the system appear seamless?

**Would direct communications with the control panels on major pieces of equipment be desirable?** Most manufacturers are taking advantage of the precision, power and flexibility offered by digital controllers and are incorporating them into the factory supplied control panels for major, technically complex pieces of equipment like chillers or variable speed drives<sup>7</sup>. Frequently, the control packages have access to a wealth of programming and operational data for the equipment served. Making a network level interface with the control package is a cost effective way to provide valuable information that would be far too costly to pick up via discrete sensors. On the other hand, an Owner might be content with picking up critical parameters via discrete connections and checking the other data when necessary via the equipment's local operator interface.

**Should the specification include requirements for compliance with BACNet, LonWorks, or other standard communications protocols?** A lot of effort has been directed at developing interoperability standards, and if you need to integrate systems from multiple vendors, *properly referencing*<sup>8</sup> these standards can provide a robust solution to the integration issue. But, specifying one of the standard communications protocols is not the only option. Many vendors offer their own integration packages to a variety of products and other systems. Systems integration houses are another option if one of the systems that you need to integrate does not support one of the standards. Specifying a standard communications protocol if you don't really need it may also work against you from a complexity or cost standpoint. A good compromise may be to specify that the system be installed in a manner that makes it physically capable of migrating to a standard like BACNet at some point in the future. Some knowledgeable specification language and shop drawings review will be necessary to ensure that the wiring, network configurations, and object definitions are arranged to allow the targeted standard to be adopted at a later date.

There are no universally correct answers to these integration issues. What matters is that they are discussed with the Owner by the design team and the results of those discussions are reflected in the contract documents.

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<sup>7</sup> See *Direct Network Connection of Variable Speed Drives* by Thomas Hartman in the March 2003 issue of Heating, Piping, and Air Conditioning for a detailed discussion of this topic as it relates to variable speed drives. The article can be downloaded from <http://www.hpac.com/>.

<sup>8</sup> It is important to understand that simply referencing the standard does not ensure integration and interoperability. The contract documents need to include the necessary language to define the specific level of interface you are trying to achieve, including object definitions, wiring and networking standards, etc. In many cases, simply specifying the standard and not covering the details associated with it can cause more problems than it solves.

The following references can provide some guidance in these areas:

- ASHRAE BACnet website: <http://www.bacnet.org/>
- Echelon website (LonWorks networks): <http://www.echelon.com/>

## Miscellaneous Components

In situations where the control contractor is furnishing their own wiring system, it may be necessary to reference the materials and methods sections of the electrical specifications to ensure compliance with project standards. As an alternative, the control specification can include the necessary requirements for conduit, wire, cable, junction boxes, and other electrical equipment for the control installation.

Regardless of the approach used, any specialty items necessary for the control installation should be included in the control specifications. Common examples include:

- Fiber optic cable and/or high speed communications cable
- Relays, pilot lights and selector switches
- Power supplies and surge and transient protection.
- Pneumatic tubing and related fittings and hardware.
- Control air supply system requirements.
- Thermometer wells, gauge ports and five valve manifolds

### 2.4.3.3. Assembly Specifications

Control systems consist of numerous small components that are brought together into a larger assembly. In some instances, including some language in the specification regarding how these assemblies are to be constructed is desirable for quality control.

Including assembly specification requirements in the following areas is often desirable.

- Control panel installation and fabrication requirements (see sidebar)
- Enclosure ratings and requirements (NEMA standard, U.L. listing, weather tight, etc.)
- Shop drawing requirements
- Component, wire, and cable labeling requirements
- Wire and tubing routing requirements as necessary to comply with the NEC low voltage wiring classifications (article 725) and minimize noise on sensitive input circuitry
- Terminal strip requirements
- Cable bundling and wire-way requirements
- Flexible wire bundle requirements for cover-mounted equipment
- Control power disconnect requirements to the extent necessary to comply with NEC
- Lighting and auxiliary power requirements
- Shop testing requirements

#### ***Control Panel Enhancements Enhance Commissioning and O&M Efforts***

*Some of the features listed for inclusion in a control panel specification are not essential for the HVAC equipment to function, but help ensure that the HVAC equipment will function as intended by making it easier to perform routine commissioning and maintenance tasks. Documentation of the component arrangements using a fabrication drawing and labels will minimize the chances of the wrong component being replaced or removed inadvertently. A neat and clean arrangement within the control panel, facilitated by terminal strips, orderly wiring runs, and a logical arrangement of components will further facilitate troubleshooting efforts. An inexpensive fluorescent lamp triggered by opening the panel door will make a difference when technicians work with small panel components in relatively dark mechanical spaces. A fused receptacle for a laptop computer or other diagnostic tools is helpful when working on a DDC system. This receptacle is not intended for hand tool use, so select a fuse that guards against this use.*

## 2.4.3.4. Operator Work Stations

The operator workstations provided for the system are the interface between the control system and the operators. Including specification requirements that will enhance this interface will be cost effective by improving system utilization and other factors related to day-to-day operations. Consider the following issues when developing operator workstation language.

### Software

**Is the specific method used to program the system important?** Current technology DDC programming approaches fall into two general categories:

- **Line-based programming code.** This method technique was originally used by most systems before the ability to easily handle graphics existed. For someone who is accustomed to line-based programming techniques, this approach can be simpler to use and can be more easily represented on text based interfaces. However, it is not as intuitive as graphic based programming and may be more difficult for non-programming oriented individuals to work with.
- **Graphics-based program code** This technique uses symbols with connected attributes to define the program. Frequently, the programs look similar to pneumatic control drawings or programming flow charts, and personnel who are accustomed to thinking in terms of logic flow charts often find this type of programming much easier to work. Editing and troubleshooting this type of code can be a challenge on some systems when there is no way to see the entire program all at once; you have to open individual windows for each element and then remember how they are linked. Other systems allow the entire logic flow to be viewed in a dynamic context.

The programming style can be an important consideration with respect to operator training, ease of use for commissioning, and ongoing maintenance. The desired programming style is a good topic for discussion with the Owner's operating staff and the commissioning team as you develop your specification. Be aware that specifying one style exclusively can eliminate some vendors from consideration, which may eliminate other equally important features. If you have the luxury of evaluating all bids and selecting your controls supplier based on other factors besides low price, then this feature can be as one of the evaluation factors used to finalize your selection.

**Is a graphic interface desirable?** Most current technology systems can communicate through text or graphics. Usually, the text-based format is the entry level, low cost approach and will be the standard supplied with your package. Text-based interfaces have the following advantages:

No software overhead to support it.

No cost required to develop the display screens that will be used by the operators.

Requires a lower level, less costly terminal for interface purposes. Usually a "dumb terminal"<sup>9</sup> can be used rather than a portable computer.

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<sup>9</sup> A dumb terminal is essentially a monitor and has very little processing power. A common example is the VT100 technology used for modem-based communications. In contrast, most system graphics are actually built up from numerous system objects and the device that displays them needs to be running software that can put the graphic together with access to the necessary files. Memory limitations in most controllers prevent the file structure and objects from being stored there. Typically the graphics are assembled from objects stored on the operator workstation hard drive and then populated with data retrieved from the field devices and controllers. This process is usually a memory and processing speed intensive.

Requires much less memory to support it.

The presentation of information that you see when you are connected to the actual controller will be nearly if not totally identical to what you see when you query the controller from the operator workstation.

The number of bytes that must be transmitted to convey the pertinent data is much smaller than for a graphic describing the same information. Thus, the response time will tend to be faster, which can be especially important if the system is being accessed over phone lines.

In contrast, a graphics-based interface will allow the system information to be presented in terms of pictures, system diagrams, and floor plans. The “picture is worth a thousand words” aspect this type of interface can often outweigh any of the advantages associated with a text-based approach, including first cost. The graphics may improve the ease of use of the system. Thus including requirements for graphics interface software can represent a wise investment in terms of the persistence of the design intent and efficiency of your project. However, there are two important things that you need to remember when you do this:

The graphic interface is only as good as the graphics it contains. Thus it is important to specify what is required in terms of graphics, a topic that is discussed [later in this chapter](#).

For most systems, it will still be necessary to use the text-based interface when connected directly to the controllers. This mode of operation usually occurs for remote access, local troubleshooting and maintenance, and in emergencies when the operator workstation is down or the network is experiencing communications problems. Thus, it is still necessary to provide training for the text based communications approach.

**Have software and firmware upgrades through the start-up and warranty year been addressed?** Most firmware and software will go through several revision cycles over the course of their use. In most instances, these revisions are triggered by new features, but they can also be made to fix “bugs” that show up in the system after it has been released to the field. In some situations, these “bugs” may not show up immediately and the software and firmware will provide trouble-free service until the triggering situation is set up in the control system. To minimize the potential for the Owner being caught off guard by a problem like this, it can be desirable to include language in the contract documents that requires the contractor to furnish and install all firmware and software upgrades applicable to the system through the end of the warranty year. This doesn’t guarantee a trouble-free future, but it does ensure that the Owner will have the best available version of the product as they exit the warranty cycle and assume full financial responsibility for the system.

**Is the ability to remotely access the system desirable?** Providing remote control system access via phone modem or the Internet can provide multiple benefits including:

- Allows operating personnel to respond to and correct deficiencies during non-normal working hours. Often, this can avert major problems and save everyone time and overtime costs.
- Allows the control contractor to provide better service during the warranty cycle and for subsequent service work. With remote access, the Owner’s favorite technician is often no more than phone call away in an emergency, even if they are on a different site or in a different state.

- Allows monitoring of a multiple locations from a central point. Owners with multiple, distributed properties can make all of the control systems available to a lead technician at a central location, thereby saving time rather than traveling from site to site.

Security can be a concern if remote access of the system is provided, but most systems have password protection and other features that minimize this risk. If this option is deemed desirable, don't forget to have the Owner arrange for a dedicated phone line to the control system location. This may mean adding a phone outlet and cable run to your contract drawings.

**Is the ability to page on alarm desirable?** Anticipatory alarms and their help in avoiding problems are one of the most important benefits provided by a DDC system. However, the alarms will do no good if there is nobody to hear them. Murphy's law states that most major building problems will occur when there is nobody there to respond. Specifying the ability to dial a pager on alarm can help put the Owner on a more even footing with Murphy & Co.. Typical features include, the ability to dial multiple numbers in sequence or based on alarm priority and the ability to send a text message describing the alarm in addition to a page. Most manufacturers offer remote paging as an option if the correct hardware is also provided. In addition, there are third party systems available that can be driven by I/O points on an existing system that cannot directly support this function.

**What other supporting software is required?** Specifying that a few additional non-control system software packages be installed and available on the operator workstation can compliment the control system software and increase its utility significantly. The following software packages should be considered:

- **Word processing** Providing a word processing package will allow the operators to create electronic log books to document their interactions, adjustments and observations while working with the control and HVAC systems. It will also allow them to create more presentable reports and other useful documents to facilitate their interactions with clients and management. In addition, the operators will have ready reference to the project specifications and other project related documents if they are stored on the hard drive.
- **Spreadsheet software** Spreadsheets will allow the operating staff to more readily analyze the wealth of data that the trending capabilities of the DDC system can make available to them. This information can be used for diagnostics as well as reporting purposes.
- **Drawing** Software packages like AutoCAD® or Viso® will allow the operators to create their own graphics, view the project construction documents, and even develop their own project documents for minor system modifications. For maximum utility, the package selected should be suitable for generating control system graphics.
- **Management** Preventive maintenance programs, purchase order generating programs, and utility tracking software are some example in this category. All of these packages will enhance the user's ability to take the data from the control system and make it more useful.
- **Reference** Many important reference documents are now available electronically. Examples include the ASHRAE Handbooks and the NFPA code books. Having this type of information readily available on a hard drive can enhance the troubleshooting capabilities of the maintenance and operating staff.

## Hardware

There are also important hardware considerations associated with the operator workstation.

**Is more than one workstation necessary or desirable?** A control system of any significant size or complexity will always benefit from a second workstation. The second workstation provides a second means of access in the event the primary workstation fails, as well as a means for the control contractor to perform routine system maintenance without interfering with the day-to-day workstation needs of the operators.

**Has a laptop computer been included in the specifications for use in programming and troubleshooting the system in the field?** Many DDC problems require observation of the system in the field in addition to observing the information presented at the operator workstation. A laptop computer with the necessary software to interface directly with the controllers allows the operating staff to access the network in the field at any controller location while they are troubleshooting rather than having to communicate with someone at the central workstation to diagnose a problem. Where budgets are limited, the laptop can serve as the second operator workstation in addition to being a portable troubleshooting tool.

**Are additional printers desirable?** Additional printers can often enhance system utility by allowing alarms to be segregated from other printed system information. A color printer with good resolution provides a means for facility staff to print graphs and other information available in the system for reports and diagnosis.

**Has enough temporary and permanent memory been provided?** CPU memory is just as important as controller memory, and technology advances have made it affordable. Providing plenty of RAM will help the system graphics load and update quickly, which is especially important when network traffic rates are high. Providing plenty of hard drive space will allow the Owner to maintain an archive of trend and utility data which will aid in diagnostics and maintaining peak operating efficiency.

**Has a means of backing up the system been provided?** The fully commissioned control system represents a significant investment in manpower. Much of this investment is reflected in the data entry associated with programming the system and in the modifications made to the initial database and tuning parameters as the system is brought on-line and operated. There is also an investment in the operating software to customize it to the needs of the project and the tastes of the operating staff. The failure of a hard drive or its controller can often eradicate this investment in a heartbeat. Thus, it is essential that the system be provided with a reliable, easy means to perform back-ups. The control contractor should develop this back-up strategy, then train the Owner in its use. The back-up strategy requirements should include documentation for the frequency of back-up, the number of copies made, and where they will be stored.

## Graphics

Graphic operator interface programs are becoming more common as the standard operating package provided on many systems. When properly developed, a good graphics package can make the control system more user-friendly to the operators. To achieve this, the specifications need to include details about the graphic requirements beyond simply stating that the system should have a graphic operator interface with a graphic for each HVAC system.

In a large facility with multiple systems, finding the graphic you need can be overwhelming. However using an intuitive strategy like a nested graphics structure that leads the operator to the correct graphic can solve this problem. For example:

- **An alarm condition can either trigger a graphic or generate a message that directs the operator to the correct graphic.** The graphics themselves can contain information on how to address the alarm as well as presenting the system in alarm. However, be aware that some care needs to be exercised when using graphical alarms. An emergency that generates multiple alarms can crash the system or make it inaccessible to operators during a crucial time period by overwhelming the workstation with graphic requests.
- **The opening screen can start with an overview that can be used to further penetrate the database in the area of interest.** For example, the system could start by presenting the operator with a graphic of the site plan. Clicking on the building of interest would open a floor plan of the building. Clicking on the equipment room area would open up a large scale floor plan with the equipment locations shown. Clicking on the piece of equipment of interest might open a graphic that is an actual picture of the machine in question with pertinent data at the appropriate locations. Buttons on this graphic might link to a schematic of the system, pictures and schematics of related equipment and support systems, and screens that allow set points to be adjusted. When using this nested approach, it is important to make sure each graphic has a button that will take you back to the screen you came from.
- **Tabular Graphics** Projects with a number of similar pieces of equipment may benefit from including a tabular style graphic in the project requirements. This type of graphic is similar to the equipment schedule on the drawings but contains dynamic updates of key operating parameters. Such an approach is useful during some testing processes as well as during emergencies when the operators need to see the big picture. It is often convenient to include buttons in the table for each system that take you to the detailed graphics associated with the system. It may also be desirable to have buttons that trigger emergency response processes, like a load shedding routine.

To achieve the utility described in the preceding paragraphs, it is necessary to include the requirements for a typical system graphic in the project specifications. In addition to the features listed above, the following issues should be addressed:

- Dynamic information will provide the greatest utility when working with graphics. Maximum permissible update times should be specified to ensure that the contractor provides a system architecture and graphic structure that provides timely information.
- Ideally, the schematics on the graphics should match the ones on the drawings (assuming they are well developed) to make it easier for the commissioning team and operating crew to correlate the control system information with the drawings. The schematics should match the actual installed field connections including the order that systems connect to headers, control valve locations (supply side vs. return side), and sensor locations (see the side bar below).
- The specification should include language that requires the data in the graphic to be legible and forces the contractor to additional graphics if one graphic cannot contain all of the desired information in a legible format.

- It may be helpful to include guidance regarding the desired connectivity from one graphic to related graphics when a nested structure is employed.
- Providing tables, switches, knobs, dials, or sliders to allow set points, start-stop commands and tuning parameters by be set via a graphic (by someone with an appropriate access level) can add utility to the system. Compared this to locating the required parameter in the point database or in the program code and to make the adjustment.

Some designers have found that a standard detail depicting the graphic format they desire is a convenient method to convey much of this information.

### 2.4.3.5. Installation Requirements

Specifying installation requirements for items that were furnished by the control contractor but installed by other trades have been discussed. It is desirable to also provide some language in the specification to help ensure that the equipment installed directly by the control contractor meets the necessary standards. Items that may merit consideration include:

- **Rough-in Requirements for Room and Outdoor Condition**

**Sensors** Room sensors may need to meet ADA or owner requirements with which the control contractor may not be familiar. Or, there may be architectural considerations or furniture layout requirements that would impact the sensors ability to perform. It is not unusual for the control contractor to be off-site early in the construction process since most of their installation cannot occur until the systems are in place. However, sensors need to be located in masonry walls, lath and plaster walls, cast in place concrete walls, or similar locations, getting them in after the fact can be difficult if not impossible. While being familiar with all of these contingencies will technically be a part of the control contractors obligation when they sign there contract, providing a few sentences of guidance in the control section of the specification to alert them to the contingencies can help avoid problems during construction for everyone.

Outdoor air sensors can be of particular concern since their performance is critical to the operation of the system. If you ask a room full of engineers and control

***Three Strikes and You're Out:** Having graphic schematics that match the actual installed system may seem obvious, but there are a surprising number of projects where the graphics are not correct. On a recent project, the contract drawings contained two diagrams of the heating water system, neither of which matched. The control schematic in the shop drawings, (destined to become the graphic) presented a third interpretation of the system. None of the three schematic drawings actually matched the schematic you would obtain if you traced out the piping as it was installed. Since the system contained 8 boilers and 11 pumps arranged in a variable flow, primary-secondary configuration, the exact order of the connections had significant operational implications in terms of the temperatures produced when the water from the various elements mixed. Interpreting the dynamic system information as it was presented on the incorrect control system graphic would have led operators to the wrong conclusions in some instances.*

technicians where the sensor should be installed, you will probably get more than one answer. Thus, it is usually in everyone's best interest for the designer specify an outdoor air sensor location on the contract documents, review this with everyone, and reach an agreement prior to actually installing the sensor.

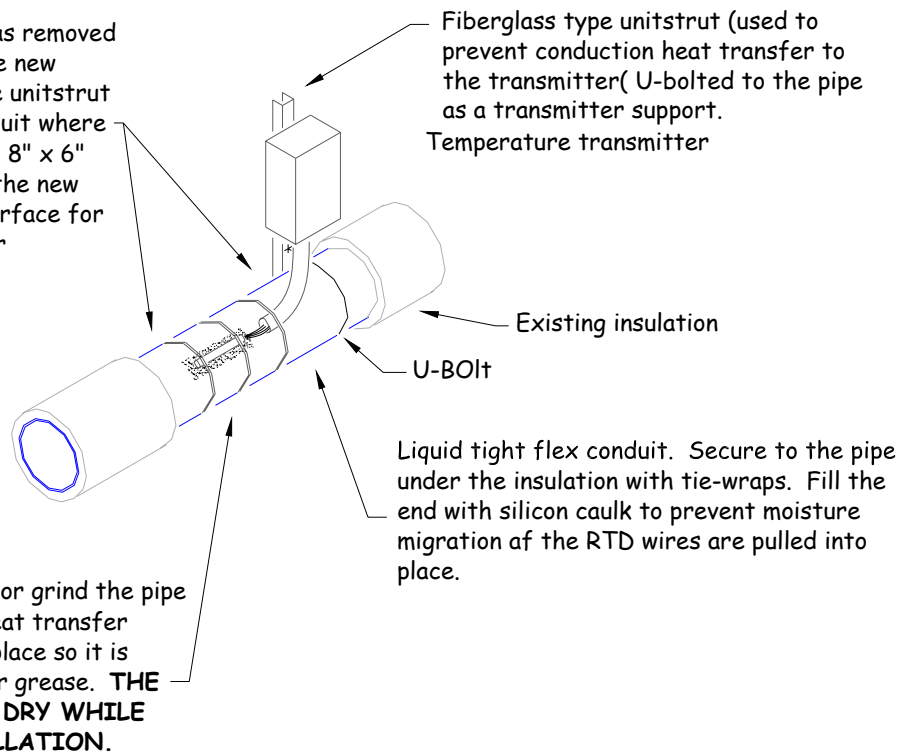
- **Sensing Element Installation Requirements** While in the general case, the control contractor can be relied upon to properly mount the systems sensors, providing some details on the drawing can ensure that your design intent is realized for specialized applications (Figure 2.7). Installation details can also help support the control contractor in situations where another trade is involved with the installation (Figure 2.8).

## **SURFACE TEMPERATURE SENSOR DETAIL**

NO SCALE

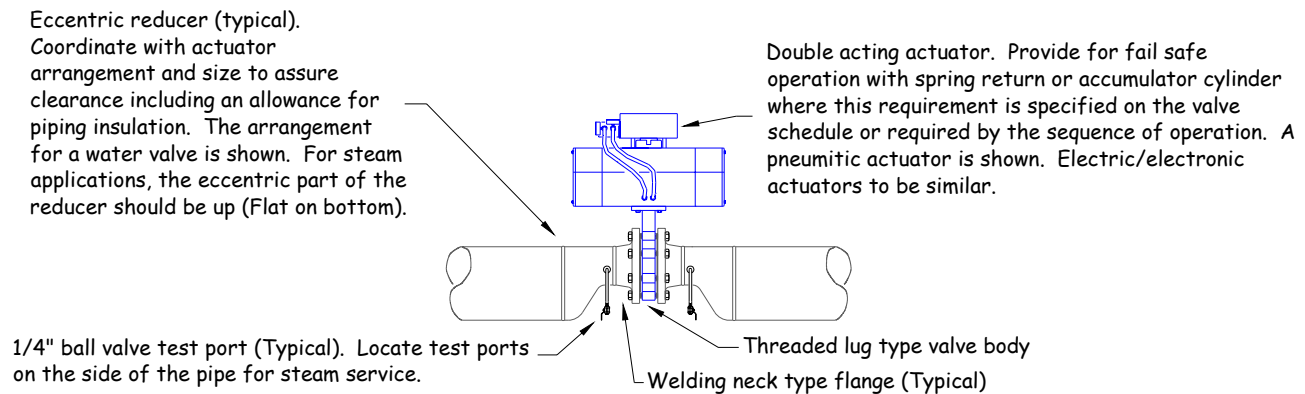
Note - At the contractors option, a strain gauge type epoxy adhered surface mount RTD may be used.

Repair the area where the insulation was removed using Armaflex or equal. Vapor seal the new insulation to the existing insulation, the unitstrut support channel, and the sealtight conduit where it penetrates the insulation. Provide an 8" x 6" removable patch over a 6" x 4" hole in the new insulation to allow access to the pipe surface for surface temperature measurements for transmitter recalibration.



**Figure 2.7 Typical Installation Detail for a Specialized Application**

AutoCAD® users can double click on this figure to open it as a drawing.



## TYPICAL 2-WAY BUTTERFLY CONTROL VALVE DETAIL

No Scale

### NOTES:

1. All two position valves to be line size unless otherwise indicated.
2. Mount the test ports as close to the valve as possible.
3. Valve for steam service to have metal seats and a heat shield for the actuator.
4. Valve for steam service to have the actuator mounted at 45° to the vertical to aid in cooling (verify suitability for non-vertical mounting with the actuator manufacturer prior to installation).
5. All two position shut-off type valves to have a double offset type disc shaft and an ANSI Class IV minimum leakage rating.
6. For modulating service, provide a positioner with characterized cam factory mounted to the actuator (pneumatic valves only).
7. For two position service, provide an electric 4-way solenoid valve assembly factory mounted to the actuator (pneumatic valves only).
8. See the specifications for sizing information.
9. Arrange fittings, flanges, and pressure taps to ensure that there is not interference with the valve disc travel over its full stroke.

### Figure 2.8 Typical Installation Detail for Multiple Trades

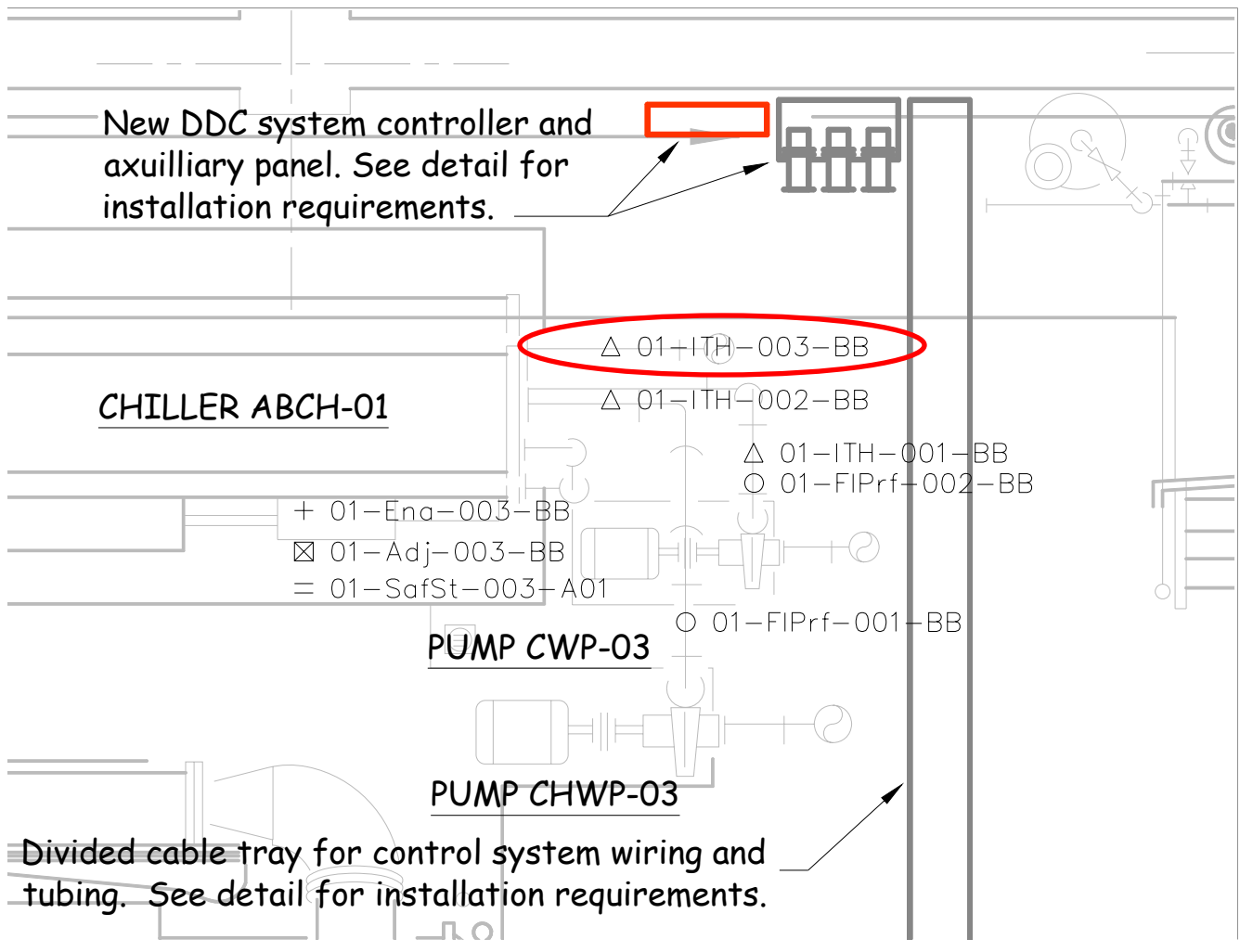
AutoCAD® users can double click on this figure to open it as a drawing.

- **Transmitter Location Requirements** A transmitter converts a low grade, noise susceptible, non-standard signal a higher grade, industry standard, noise immune signal so that it can be passed over distance without degrading. In other words, it is more than just a signal converter and the project documents should ensure that transmitters are installed in a manner that fully utilize the benefits they provide. This is discussed in more detail in the Functional Testing Guide, *Chapter 5: Supplemental Information*, Section 5.6.4.4.
- **Five Valve Manifold Requirements** Differential pressure sensors can be subjected to decalibration or even destroyed if their sensing elements are exposed to full line pressures. Valve manifolds with equalizing connections can avert this and should be specified where applicable. This topic is discussed in greater detail in *Chapter 3*, Section [3.5.3.2: Five Valve Manifold](#).
- **Pneumatic Tubing Related to Smoke Control** The tubing serving smoke control dampers may have special installation requirements in certain jurisdictions including the need to run all copper to minimize the potential for a tubing failure during the early stages of a fire. Such requirements should be clearly stated in the control specifications.

- **Tubing Used to Connect the Sensing Ports of Transmitters that Monitor Low Pressures to the Location Where the Pressure is Sensed** The long tubing runs frequently used bring low air pressure signals to a static pressure transmitter can cause problems related to their length and leakage. These issues are discussed in detail in the Functional Testing Guide, *Chapter 5: Supplemental Information*, Section 5.6.4.4. Specification language or installation details should clearly direct the contractor with regard to your expectations for this type of application.

## 2.4.4. Floor Plans

Developing floor plans for the control system is beyond what most designers typically include in their process. However, those who can afford to go this extra step, will see benefits during the bidding, construction, and operation phases of the project that help ensure a quality product. The ideal control drawing background will include both the mechanical and electrical systems since the control system generally must interface with both. Developing this type of background is fairly easy due to the external reference capabilities of CAD programs. Another option that may further reduce the effort is to include the information on the project's mechanical or electrical sheets rather than generating a separate set. The illustration in Figure 2.9 was extracted from a control drawing set to illustrate control system floor plans.



**Figure 2.9 Mechanical Room Drawing with Control Information**

The background for this floor plan was generated quickly in AutoCAD® by external references to the mechanical and electrical drawings. The control information and points were then inserted. The points have AutoCAD® attributes associated with that are entered when they are inserted on the drawing. An automated AutoCAD® procedure can be used to extract this information to generate a point list. Most of the attributes are invisible, but the point number is displayed along with the point symbol. The coding of the point number reveals useful information about the point. For instance, the number circled in red is coded to indicate the location (the 01 for the central plant), the sensor type (Immersion Temperature, High precision), the number (003 for the third point of its type), and is furnished under the base bid (BB). AutoCAD® users can double click on this figure to open it as a drawing.

From the designer's perspective, developing the floor plans provides one last cross check for coordination issues, especially if the control drawings are developed as a separate set using references to both mechanical and electrical sheets. Thus at least a portion of the development costs associated with the set can often be written off against coordination checks that are normally done as a part of any design process.

Providing floor plans for the bidding phase allows the contractors to better understand and coordinate their work. Having floor plans with important control system information on them allows the controls contractor to devote their time during the bidding window to tailoring their equipment and system to the requirements of the project rather than to developing a basis for obtaining a wiring price. As a result, the controls contractor will generally have a higher level of comfort with their bid and will feel comfortable bidding at lower profit

margins since the enhanced understanding of the project can reduce their risk. The floor plan information also helps ensure that the bids from different vendors reflect equivalent systems.

The benefits of having floor plans as a part of the construction drawing and record set are more obvious. The information will help contractors interface with control work, help the owner and operators become familiar with the building controls, help the designers communicate their intended design, and help the commissioning provider put together commissioning specifications before all of the control drawings are available. Items that might be included in the floor plans are:

- Point locations
- Major cable routes
- Power sources and wiring requirements
- Controller and auxiliary panel locations
- Operator work station locations

## 2.4.5. Standard Details

Standard details for the control system allow the designer to ensure that the control contractors meet the design intent. Obviously, developing these details will take some initial effort, but once they are developed, they can be used again and again with minor modifications as required to meet the project's specific needs.

Given the wiring intensive nature of DDC systems, detailing wiring requirements can provide important guidance for the construction team. At first, this may sound like a time consuming and difficult area to detail due to the many manufacturers and systems available in the industry and the perceived complexity of the technology. However, if the focus of the effort is to show intent rather than system-specific information, developing the details can be a fairly simple, one-time process, that will improve the quality of the project when included in the designer's construction documents. Often, the necessary details can be developed from information included in the control shop drawings associated with a past project.

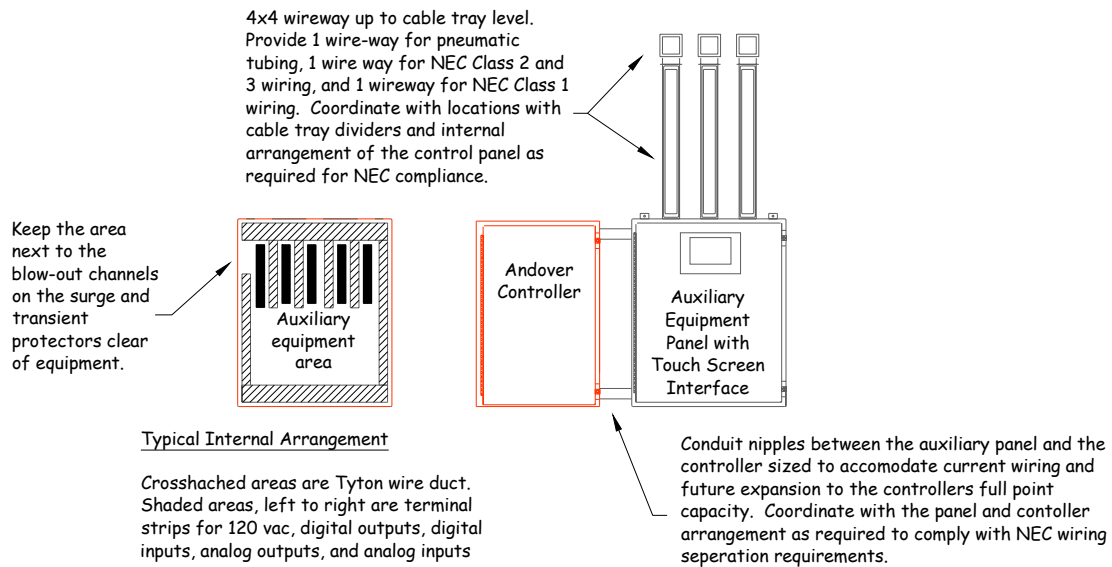
The benefits of developing these details are similar to those achieved by providing floor plans. The contractor can more easily develop a better price since intent is conveyed to all parties in the process. Specification language and/or notes can clarify that the details are intended to provide guidance during the bidding process and that the contractor is still required to develop system and project-specific wiring information as a part of the control submittal package. Typical wiring details might include:

- Control panel power requirements.
- Control panel arrangements.
- Input and output wiring for the various input and output types.
- Starter interlock wiring, including permissive type interlocks.
- Variable speed drive interlock wiring.

Other areas where detailing can provide significant benefit include.

- Sensor installation requirements
- Typical graphic requirements
- Typical damper and valve requirements
- Control panel requirements

Figures Figure 2.10 and Figure 2.11 are examples of some details of this type.



## TYPICAL CONTROL PANEL DETAIL

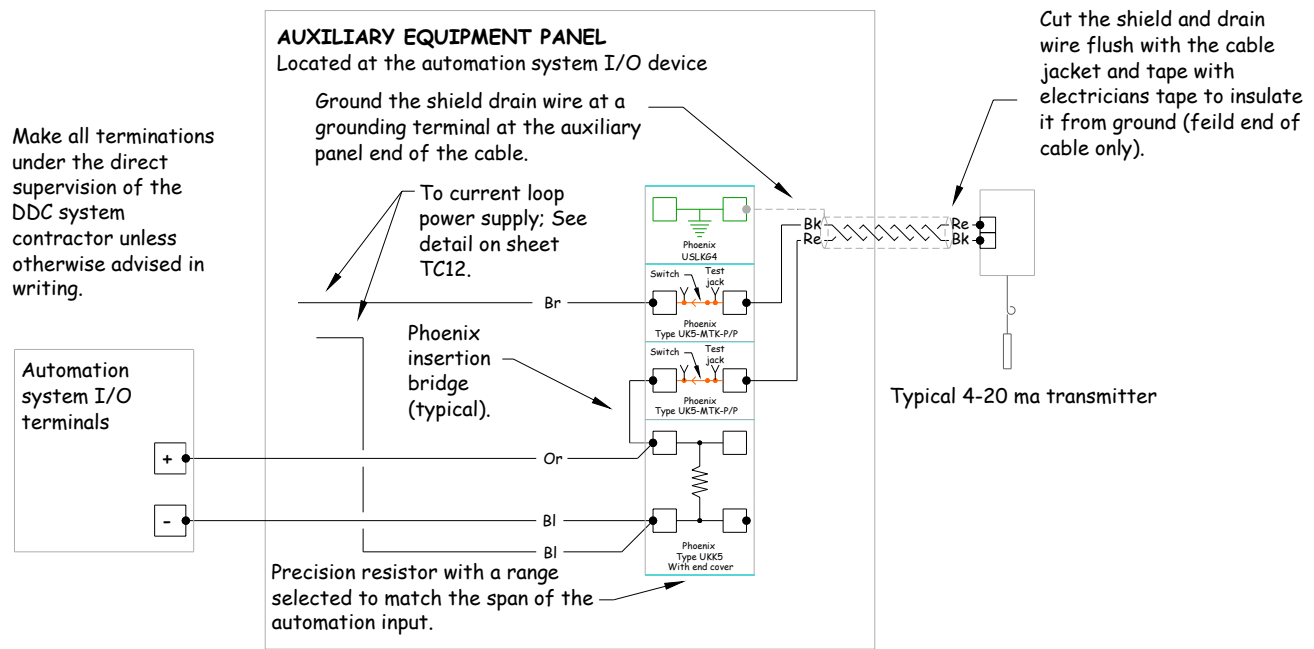
No Scale

Notes:

1. Coordinate the exact arrangement of the control panel with the project engineer and Owner during the shop drawing process.
2. Provide a touch screen interface panel on the cover of one auxilliary panel in each control room. See the specifications for programming requirements.
3. Mount panels with the top 5'0" AFF unless otherwise directed.
4. All panels to be NEMA 12. Coordinate with the controller manufacturer as necessary to determine size requirements for cooling or provided cooling equipment that does not violate the enclosure rating.

### Figure 2.10 Typical Control Panel Detail

This detail is from the same project as the floor plan that was used in Figure 2.11. AutoCAD® users can double click on this figure to open it as a drawing.



## TYPICAL ANALOG INPUT WIRING

NO SCALE

This detail is provided to illustrate intent and to facilitate bidding. The successful control system contractor shall provide similar details that are edited to be specific to the requirements of their system as a part of their shop drawing package.

**Figure 2.11 Typical Analog Input Wiring Detail**

This wiring detail illustrates an analog input using several of the specialty terminal strips discussed here and in *Chapter 3: Control and Monitoring Points*.

The specialized terminal strips shown in the typical diagram in Figure 2.11 bear special consideration and discussion. While quite common in the industrial and process control systems, the technology represented by these terminals has yet to penetrate the HVAC industry. This is partly because designers are simply not familiar with it, and partly because it is seen as an unnecessary added cost. From a commissioning and operations perspective, the functional benefit from these devices can outweigh the minor costs associated with their installation. From a lifecycle perspective, the first costs are often saved during the start-up and first year of operation.

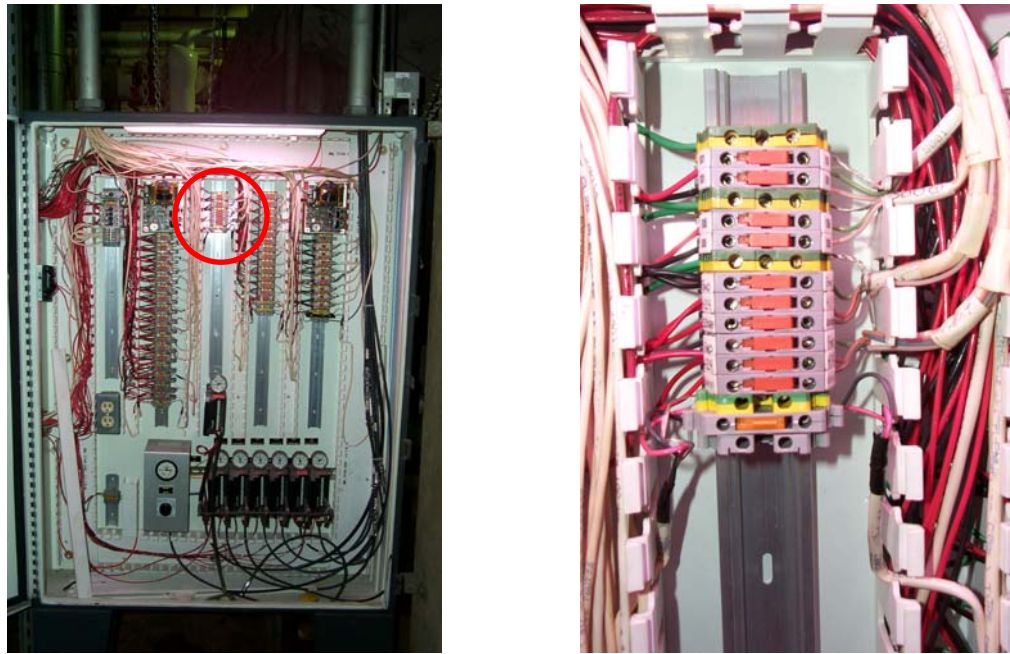
The benefits of terminal strips include:

Identification of wiring to speed up maintenance and troubleshooting and minimize confusion and mistakes.

- 2 On projects where the sensors and their wiring system are installed by an independent contractor, the terminal strips can be used to define the contract boundary between the wiring contractor and the control contractor.
- 3 Input signal quality persistence can be improved in some applications by minimizing problems with poor connections that can occur when solid conductors like the leads from scaling resistors are clamped under the same terminal as a stranded wire (see [Chapter 3, Section 3.3.4.3 Scaling resistors](#)).
- 4 Easier troubleshooting because the terminal strips provide a standard wiring arrangement, thus a standard troubleshooting procedure can be developed. Often, this will allow the initial troubleshooting effort and some repairs to be accomplished by a lower level technician, which reduces costs and frees up other staff members. In the long-term, terminal strips make future controller upgrades easier to accomplish. Most of the technical evolution that has occurred in the DDC field occurred at the controller, network, operator work station, and sensors. Future evolution will undoubtedly continue in these areas. Despite these changes, the wiring requirements associated with the inputs and outputs seen on most HVAC systems have changed very little, especially in situations where standards like 4-20 ma, 1-5 vdc, etc. have been employed. Thus, while technological improvements may result in Owners upgrading some of the hardware in their systems, the wiring system can often be retained and re-used. Terminal strips can make controller and sensor upgrades easy to accommodate, further reducing the costs associated with the improvements. The case study in the sidebar illustrates this advantage.

***The Old Serves the New:*** Early recognition of the advantages of centralized monitoring and control caused a Midwestern University to develop and install such a system starting in the early 1980's. The system started out as a supervisory monitoring and control system for critical buildings and evolved as time and budget allowed. From the beginning, standard input and output strategies like 4-20 ma, platinum RTDs, and 3-15 psi had been used, and field wiring had been terminated using specialty terminal strips similar to those described in this chapter. In the late 1990's, a project to replace the original programmable controller and IBM Series 1 mainframe technology with state-of-the-art DDC technology and creating the infrastructure necessary to make DDC the control standard for all future projects. When the project was implemented, the installation costs in many areas were mitigated by the fact that the original I/O wiring and sensors could be re-used. The utility provided by the existing terminal strips also reduced changeover and check-out time, saving an estimated 40 to 60% of the costs normally associated with a control system replacement.

Figure 2.12 takes a close look at typical specialized terminal strips.



**Figure 2.12 Typical specialized terminal strip installation**

The area inside the circle on the left is shown in the right picture. These terminals ground the shields for the I/O cables (green and yellow terminals), allow field wiring to be isolated for testing (orange terminals) and scale analog inputs (bottom terminal).

## 2.5. Putting These Concepts to Work

By providing some or all of the control system design features discussed in this chapter, a designer can improve the quality of their projects as well as distinguish themselves from other consultants to a savvy Owner, thereby improving profit margins and client relationships. The information and tools provided in this chapter will help put these concepts to work. The remaining chapters in the Control System Design Guide serve the following functions:

**Chapter 3: Selection and Installation of Control and Monitoring Points** Chapter 3 describes sensor technologies, sensor accuracy, installation issues, sensor selection and installation guidelines, and the point interface to the building automation system. The sources of error in a measurement, from the sensor to the control system workstation are described in detail.

**Chapter 4: System Configurations** Chapter 4 includes sample point lists for many common system configurations. These lists can become the starting points for future projects.

Many of the fundamental building blocks required for the control system design process are available within the Control System Design Guide. One of the best ways to get started on the process is to choose a relatively simple project for the initial effort, perhaps one that has only one or two air handling systems that serve a few zones in a standard configuration. The details and specifications developed in this initial project can then serve as stepping stones to larger, more complex projects in a path to improved control system design and better functioning, more efficient HVAC systems.

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## 3.1. Introduction

Selecting control system points not only requires knowledge of the system design intent, but an understanding of how the system will be commissioned and operated for the life of the building. Including the commissioning and building operations perspective when selecting control and monitoring points will go a long way toward achieving a more easily operated building. This chapter draws upon commissioning field experience to help designers, commissioning providers, and contractors install appropriate control system points for well-functioning HVAC systems.

Chapter 3 is organized from the general to the specific. Recommendations for selecting input (i.e., sensors) and output points (i.e., commands to actuators) are presented along with practical advice for installation. Understanding sources of sensor error, from the sensor to the control system workstation, helps designers avoid these errors and helps commissioning providers interpret inaccuracies in the field measurements. Additional issues such as safety points and calibration guide installation. Next, sensor selection and installation guidelines identify sensor requirements based on application. For example, the temperature sensor requirements can often be very different for space temperature and chilled water supply temperature applications. With a limited budget for control and monitoring points, the sensor selection guidelines steer efforts toward high-impact control and monitoring decisions. Recommendations for interfacing points to the building automation system (BAS) include discussion of the details central to making the BAS workstation a useful tool for operators.

Specific issues regarding damper selection and control are covered in the Functional Testing Guide for Air Handling Systems (Functional Testing Guide), *Chapter 5: Economizer and Mixed Air*, Section 5.6.1 Dampers. This chapter is also the educational component behind the point lists in *Chapter 5: System Configurations*.

## 3.2. Point Selection

Through careful control and monitoring point selection, designers can enable efficient control, measure system performance, and perform diagnostics. This section gives tips for selecting points that result in more easily controlled and maintained HVAC systems.

### 3.2.1. Temperature Between Each Cooling or Heating Element

While all temperature points may not be critical for basic control, having temperature measurements between each cooling or heating element helps diagnose operational problems such as leaking control valves, simultaneous heating and cooling, and poorly calibrated sensors.

In the following example, adding a preheat temperature sensor illustrates the usefulness of points for diagnostics. Consider the case in which a designer includes a hot water coil in the HVAC system purely for a warm-up cycle since the outdoor air requirements did not result in a need to preheat. As a result, the control sequence simply controls this hot water coil based on a space temperature during the warm-up cycle then shuts the coil down at all other times. A coil discharge air temperature sensor is not included because it is not need for control. However, including the sensor as a part of the base design would provide the following immediate and long-term benefits.

- The commissioning provider could trend the point during the commissioning process to verify that coil was not being activated inappropriately.
- If functional testing revealed that the performance of the control loop under the warm-up cycle was unsatisfactory based on discharge temperature due to system time constants or other unanticipated issues, the sensor in the coil discharge would provide an easily implemented alternative control loop input.
- The discharge temperature sensor can indicate a temperature rise across the preheat coil when the preheat valve should be closed. Operators could be notified of this problem through a BAS alarm that evaluates preheat discharge temperature, outside air temperature, and outside air damper position. Alarms that involve comparison or calculations are often called “smart alarms”, which are described in more detail in [Section 3.6.4 Programmable Alarms](#).
- If a change in the owner’s use of the space occurred that affected the census in the space, the systems minimum outdoor air requirements could be increased. The coil might need to perform some modest preheat function during extreme weather. Having an existing sensor in the coil discharge could be used in the preheat control loop without hardware additions and their associated wiring and sensor costs.
- Instead of fully opening the hot water valve for freeze protection, the preheat discharge temperature sensor can be used to modulate the hot water valve to keep the air handling unit above freezing when the unit is not operating. Fully opening the hot water and chilled water valves for freeze protection has adverse effects, which are described in the Functional Testing Guide in *Section 9.5.4.1 Freezestat Control Sequences*.

### 3.2.2. Motor Command Signal and the Motor Status

The digital output that commands a motor to start and stop and the digital input that shows a motor’s on/off status should both be available at the operator’s interface to the control system. The digital input status point is not required to operate the system, but is useful as a troubleshooting tool because it proves that the motor has correctly responded to the command by the digital output. If the value of the command point does not correlate with the value of the status point (for instance the fan is commanded on, but the status point says that the fan is not running) then the drive or motor starter may have been switched to a manual mode. For VFD diagnostics, the motor speed command and speed feedback from the motor can be compared. Smart alarms can alert the operator when the motor speed does not vary over a significant period of time, signaling a potential problem with the VFD. Operator responses and smart alarms need to take into account that there is often a time delay between when a command is sent and when the workstation displays the command or feedback.

To pick up the proof of operation information, a number of techniques can be used. Contrast the following options for a status point for a supply fan.

- **Option 1: Motor Starter Auxiliary Contact** Monitoring the motor starter auxiliary contact is probably the least expensive approach to obtaining a motor status point, but it is only an indirect indicator of motor status. The point does not prove that the fan is running, but only that the starter engaged. If the belt or drive coupling to the fan has failed, this failure would go undetected until some other parameter (like loss of control of space temperature) became evident. Even then, the starter auxiliary contact would not be a direct indication of a drive failure since there are often other things that could cause problems.
- **Option 2: Fan Differential Pressure Switch** Monitoring the fan differential pressure switch is slightly more expensive than Option 1, but it has the advantage of

proving that the fan wheel is actually rotating, thus the drive system is intact. However, this point does not necessarily prove that the fan is moving air since a fan will produce pressure without necessarily producing flow. If the fire dampers in the system closed or the smoke isolation dampers or intake dampers did not open, the fan could start and produce a pressure difference which would be seen by the differential pressure switch and interpreted as proving the fan's operation. In this case, the fan is operating, but the intended system function of moving air is not being provided.

- **Option 3: Differential Pressure Switch Across Several AHU Elements** If the differential pressure switch associated with Option 2 is piped across several AHU components that only produce a pressure drop if there is flow, then the switch will not only prove that the fan has started, but will also prove that there is flow in the system. Adjustment of this switch can be critical on VAV systems since the pressure drop will vary with the square of the flow rate. For instance, when the system unloads and reduces its flow rate to 50% of design flow, the pressure drop through the air handling unit components will only be 25% of the design value. If the switch was only piped across one AHU element, the pressure drop at low loads could be difficult to detect reliably and could result in the switch erroneously indicating that the supply fan was not running. Piping the switch across several elements provides a larger signal to work with.
- **Option 4: Motor Current Switch** Motor current switches provide a fan proof of operation point similar Option 3 since the motor current will also vary with load. The first cost will be lower than the differential pressure switch because the current switch can be located in the starter. This location also reduces wiring costs compared to the differential pressure switch because the switch is installed at the same location as the start-stop command and can be picked up by running a second cable to this location.

Properly adjusting these switches on VAV systems can offer similar challenges to those mentioned in Option 3. At 50% of design flow, the horsepower requirement is 1/8 of the design value, since the motor load varies as the cube of flow. A low current at a low load condition should not be mistaken for no supply fan operation. In addition, other parameters that vary with the load also affect motor current, like motor efficiency and power factor. As a result, finding the correct setting for a current switch on a VAV system can take some experimentation. Often, it is easiest to determine the correct current switch setting during the belt re-tensioning effort<sup>1</sup> at start-up. The motor current should be measured at no load with the belts off and at minimum turn-down. Then adjust the switch to prove operation only when the current exceeds this value. This process can be time consuming and may not be worth the expense on smaller systems.

### 3.2.3. Control Loop Execution Over the Network

The input to and output from a single control loop should be hardwired to the controller where the loop statement resides. As a general rule, a control loop should not be executed over a communications network.

Consider this scenario for a fan discharge static pressure control loop. The input duct static pressure is wired to a remote terminal unit and sent to the air handler controller over the communications network. The output of the PID loop at the air handler controller is then sent over the network to control a VSD. What would happen to system control if the network crashed? A network failure puts the system in an open loop mode. Information would not be

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<sup>1</sup> Belts will tend to stretch slightly when they are first installed and tightened. So, ideally, they should be retensioned after 8 or so hours of operating time has been accumulated. Coordinating the commissioning of the current switch settings with this effort can save time because the belts can be loosened to the point of no load and then retensioned.

available to the operators, and the system would be controlled by either the last data that the controller received or a default value. To avoid these problems, all inputs and outputs for a control loop should be hardwired to the controller that performs the loop statement.

Another reason to avoid sending control loop inputs and outputs over the network is to prevent the network communication rate from interfering with the control loop. When a network slows down due to network traffic, tuning control loops becomes extremely difficult, since the time constant for loop response becomes inconsistent. Evidence of variable network performance may be apparent in the variable time required to update workstation graphics.<sup>2</sup>

In older systems, the loop statement is often located at the host computer, since older controllers lack the computing power to perform loop calculations. As a result, both the input and the output data for the loop is transmitted over the network. In newer systems, the control loop can reside at the air handler controller, with the input hardwired to the controller and the output hardwired to the actuator or drive. And on some current technology networks, the loop can reside in the VFD drive controller. If this approach is used, then the control loop that controls the drive should be located in the drive controller card, and the input that is used by the controller should be wired to the drive controller card where it can be used directly by the control loop without network interaction.

Sending control variables over the network may be inevitable with the use of application specific controllers with control algorithms that are not available pre-programmed into the controller (see sidebar). In this case, the control logic must reside on a higher-level network controller, with the controlled variable sent over the network. This approach should be used with caution and evaluated with regard to what happens if the network were to fail. In some cases, the result would not be critical to building performance or system integrity and could be tolerated as long as the failure was detected and corrected.

Sending interlock commands over a network should be considered on a case-by-case basis. In some instances, using software interlocks can provide economy in terms of first cost by substituting programming for hard wiring with little loss in system integrity, performance or safety. But, in other cases, a network problem could impose severe operating and safety

*Consider a loop that controls the building relief dampers where the relief damper command resides in the controller, but the loop must run at a network controller because the application specific controller does not support building pressure based control of the relief dampers. Upon a network communications failure, if the system was configured to alarm and hold the relief dampers at the last setting, then the approach may be acceptable. On the other hand, if the loop that resides on the network controlled the supply fan speed based on duct static pressure, an open loop situation due to a network failure could place the duct system in danger of over-pressurization and an inability to meet the load. In this case, an application specific controller (with the control loop executed over the network) may not be an acceptable alternative for the system.*

<sup>2</sup> If there are detectable differences in the graphic update times, they are probably due to differences in the network communications burden at the times the graphic was called up to the console. If the delay times run into the range 30-60 seconds or more, then network communications problems may be significant enough to make the system difficult to use, especially in an emergency.

penalties on the system if the interlocks are accomplished in software. In these situations, hardwired interlocks should be implemented.

### 3.2.4. Network Card to Obtain Monitoring Points

**For a piece of equipment with many output parameters, like a VSD, fire alarm panel, or chiller panel, using a network card that interfaces with the control system is an economical way to obtain operational information.**

While the input to and output from a single control loop should be hardwired to the controller where the loop statement resides, other points such as the start/stop command and proof of status feedback can sent across the network since they are generally not continuously varying processes and are not part of the control loop.

For example, the following VSD points should be available through the network card:

- **Proof of Operation**
- **Speed feedback** This point is not absolutely mandatory, but is highly desirable to ensure that the drive is responding appropriately
- **Selector switch status contact (hand/auto/off, and inverter/bypass)** This point is not absolutely mandatory, but also highly desirable. This point allows an alarm when the piece of equipment has been put into a mode where the drive is not functioning. One point with a general alarm can be used for to monitor both switches.

For the cost of a network card and twisted shielded pair, the numerous parameters that go along with the drive are available, including start/stop, feedback proof of speed, status contact, current, kW, faults (programmable), and diagnostic points. Since these points can be obtained by the network card instead of hardwiring, more controller I/O capacity is available for other points. A network card can access many points and drive parameters for less money than would be spent hardwiring. The catch is that the network card must allow the VSD and control system to communicate. The communications card, VSD, and control system should be compatible with a common network connection protocol such as LONworks, BACNet, or IEEE standards. As an alternative, many drive manufacturers offer special drivers or cards to interface their equipment to the proprietary communications protocols used by the various control systems manufacturers.

Similar considerations apply when networking other equipment such as chiller or boiler control panels, lighting control panels, security or access control panels, or fire alarm panels. Fire alarm and security panels may require additional considerations related to maintaining the integrity and security of the system. These considerations may make a network interface to these devices impossible, impractical, or undesirable despite the technical benefits that could be achieved.

### 3.2.5. Monitoring and Diagnostic Points

Monitoring and diagnostic points serve three main purposes: to understand system performance, to add flexibility to the system, and as a tool for tracking maintenance needs. Monitoring points are often utilized for manual or automated system diagnostic methods to detect problems. Smart alarms can notify the operators of these problems (see Section [3.6.4 Programmable Alarms](#) for more on smart alarms).

Examples of monitoring and diagnostic points include: fan amps, total HVAC power, supply fan flow, cooling coil capacity, and ton-hours. A full list of recommended monitoring and diagnostic points is included with the points lists in Chapter 5. Generally, it will be less expensive to install monitoring points during the initial construction work rather than later, and the costs can be carried by the project's construction budget. If the point must be added during the start-up phase in response to a commissioning need, the operations staff may need to find alternative funding outside of the project budget, which is not always an easy task.

**Systems will last longer than the current design conditions will exist, so it can be beneficial to design systems to be adaptable to changes in operation.** Due to overestimations in design loads, most systems have some margin to handle load changes that may occur over time. The trick is designing a system that can adequately serve the peaks and future load requirements while efficiently serving the present and future load conditions.

**Monitoring points also provide valuable information for maintenance.** For example, points that notify the operator of a high filter pressure drop are especially important for detecting dirty filters in VAV systems since the filter pressure drop varies with flow. If visual monitoring is done, the filter pressure could look normal in the morning at low flow conditions when the operator made his rounds, but have pressure drops in excess of the filter structural rating at peak load in the afternoon when nobody was there to notice it. As a result of excessive pressure drops, some filters could fail. Air would bypass the filter banks and lower the net pressure drop on the filter bank. In this condition, the filters could be mistaken to be clean if the filters were not visible. These problems could be avoided with continuous monitoring of filter pressure drop at the workstation. More examples of monitoring points for maintenance are listed below:

- Accumulated run hours for pieces of equipment to help schedule preventive maintenance
- Data to calculate the operating cost for a system
- Proof of operation input current switches to alert maintenance staff to motor problems. The current switch should be able to tell the difference between a fan running at low load and a broken belt or coupling.
- High and low water level alarms for evaporative coolers to indicate loss of make-up water and overflow conditions.
- Make-up and blow down rate for evaporative systems. Owners can to reduce their sewer charges by the amount of water that was evaporated in utility districts where the sewer charge is based directly on the water consumption.
- Pressure relationships in critical applications like healthcare and clean rooms. While this monitoring can be accomplished manually via testing with hand-held equipment, continuous monitoring will catch a problem sooner and frees staff up for other tasks.

Be careful not to overdo it – adding monitoring and diagnostic points is not always cost effective. When prioritizing the importance of monitoring points, think about how often the data will be used, what the data will be used for, and the implications of detecting problems.

### 3.2.6. Additional Points for Advanced Control Strategies

Additional points may be necessary to implement advanced control strategies. Examples of advanced control strategies associated with air handling equipment include building pressure control and demand control ventilation (based on occupancy status of room or CO<sub>2</sub> levels).

Some buildings are beginning to employ strategies that limit demand during peak times. These strategies may require monitoring of end-use power (to understand where demand reductions have occurred), zone temperatures (to measure the impact on occupant comfort), and zone air flows (to verify that indoor air quality is maintained). In some cases, these demand reduction strategies are being implemented to engage automatically during high prices or requests by the utility for demand reduction. The interface of the control system with the pricing information is not an easy task.

### 3.3. Sensor Accuracy

Specifying the desired accuracy of sensors is not as straightforward as it sounds. Sensor accuracy should be specified with an understanding of the different ways in which manufacturers can present the accuracy as well as with an understanding of the requirements of the sensor application. The following information about sensor accuracy describes potential sources of error in readings and how accuracy can degrade over time. There is potential for error at each step of a control or monitoring measurement – at the sensor, transmitter, wiring, controller, and operator workstation.

Consider all the steps to read an accurate temperature measurement from an RTD with a transmitter. First, the RTD must accurately vary its resistance in response to temperature. The sensor resistance is converted to a voltage, and this voltage is converted to a 4-20 mA current signal by the transmitter. Then, the current travels down a length of wire to the controller where it is converted back into a voltage signal, typically by

#### **Advanced Control Strategies -**

#### **Advanced Operating Problems:**

*Advanced control strategies such as discharge temperature or pressure reset can be desirable in terms of saving energy and improving overall system performance. However, they must be applied with caution and consider the specific needs of the system. “One size fits all” application of advanced strategies leads to problems.*

*For example, discharge temperature reset routines can make a variable volume system look more like a constant volume reheat system if not properly implemented. The higher leaving air temperature from the reset strategy can cause critical zones to demand more flow, lowering the system static pressure and speeding the fan up, in some cases to 100%. Resetting strategies combined with PI or PID loops can often make system extremely unstable. If the setpoint is continuously optimized based on other system parameters, then having a PI loop busily working to eliminate proportional error may not be necessary since the reset routine may correct for the proportional error automatically. Making the loop Proportional-only will lower first cost, make the system more stable, and make the system easier to operate and maintain. Sophisticated control strategies applied as “canned” routines can increase operating costs and reduce efficiency – the opposite of their intended effect.*

using a scaling resistor. The controller routes the signal through an analog-to-digital converter with a certain resolution (8-bit, 12-bit, etc.) and sends the digital signal via a network protocol to the host computer. The analog-to-digital converter and all of the other electronics on the circuit board have tolerances associated with them that can impact the signal quality. The way the data is handled and truncated to send it from the controller to the workstation is also important to prevent minor changes from creating a flurry of activity on the communications network. The bottom line is that at each mechanical or electronic interface, there are a number of opportunities for error.

A good understanding of sensor accuracy issues serves both designers and commissioning providers well. By understanding the many ways accuracy can be affected, designers can write clear specifications for sensor selection and installation that result in reliable measurements. Commissioning providers inevitably find erroneous data in the field, and an understanding of measurement error gives valuable insight into troubleshooting these errors. When interpreting test results, commissioning providers should keep in mind that the data may not reflect the true conditions for a variety of reasons related to sensor accuracy and the data handling characteristics of the system. Going one step further, the commissioning provider should test the systems with these possibilities for error in mind. The sources of measurement error presented in this section, from the sensor to the DDC workstation, will help users better understand the complexity of sensor measurements in control systems.

### 3.3.1. Sensor Error

Both the RTD element and the transmitter electronics package have accuracy issues related to a number of factors. Sensors are manufactured with a given measurement tolerance and sensitivity. Some sensor measurement errors are due to a lack of persistence of calibration, while other errors are intrinsic to the sensor and the way in which it was installed.

Precision field calibration of sensors can be difficult, time consuming, and costly. One way to solve this problem is to have the manufacturer supply calibration certificates for each sensor that demonstrate that the sensor has been appropriately calibrated at the factory. Section [3.4.4.1](#) gives more information on using factory-calibrated sensors.

Sensor accuracy takes into account all deviations between a measured value and the actual value. Three common ways of measuring sensor accuracy are:

- Percent of a sensor span (i.e.,  $\pm 0.5\%$  of the  $0^{\circ}\text{F}$  -  $100^{\circ}\text{F}$ )
- Percent of sensor reading (i.e.,  $\pm 0.5\%$  of the  $50^{\circ}\text{F}$  reading)
- Absolute accuracy (i.e.,  $\pm 0.5^{\circ}\text{F}$ ).

For example,  $\pm 0.5\%$  of the reading for a  $0^{\circ}\text{F}$  -  $100^{\circ}\text{F}$  transmitter is more accurate than  $\pm 0.5\%$  of span. An accuracy of  $\pm 0.5\%$  of reading is  $\pm 0.175^{\circ}\text{F}$  at  $35^{\circ}\text{F}$  and  $\pm 0.475^{\circ}\text{F}$  at  $95^{\circ}\text{F}$ , while an accuracy of  $\pm 0.5\%$  of span is  $\pm 0.5^{\circ}\text{F}$  at all temperatures. By reducing the span, accuracy can be increased. Sensor accuracy can be specified for a sensor alone, a sensor-transmitter assembly, or all inclusively from the sensor to the workstation. If a  $100\Omega$  platinum RTD with a 4-20 mA transmitter was rated for  $\pm 0.5^{\circ}\text{F}$  as an assembly, then you should expect that any sensor and transmitter manufactured to that specification will have an accuracy of at least  $\pm 0.5^{\circ}\text{F}$ .

A sensor's accuracy may be affected by:

- Non-linearity
- Hysteresis (the difference in a measured value when approached from above and below).
- Mounting location effects (heat and vibration)
- Thermal drift (thermal cycles that degrade electronics accuracy over time).
- Transmitter components calibration errors related to their tolerances
- Self-heating of resistive sensing elements. The measuring current required for the sensor output signal heats the element itself. The error depends on the heat-shedding properties of the sensor's materials, construction, and the temperature of the environment.  
(Reference: See Minco Resistance Thermometry, Application Aid #18.)

### 3.3.2. Sensor Wiring Errors

The way in which a sensor is wired to the controller can also reduce accuracy. Overcoming lead wire resistance using current loops can be a more robust method for getting information from the field device to the controller than measuring voltage (with little current flow in the input wires). Properly shielding and twisting the input wire results in more reliable measurements by minimizing the potential for electrical noise.

#### 3.3.2.1. Lead wire resistance

The added resistance from the length of wire connecting the sensor to the controller is called *lead wire resistance*. Lead wire resistance results in errors for resistance type sensors. The higher the resistance of the RTD sensor, the less the lead wire length affects the RTD accuracy, since the lead wire resistance itself accounts for a smaller fraction of the total resistance.

There are three components to the lead wire resistance problem. One is the resistance added to the circuit at any fixed temperature simply due to the length of the leads. This effect can easily add a degree or more of equivalent resistance to the circuit that has nothing to do with the measured value. Given time and sufficient instrumentation, this error could be field calibrated out of the circuit using scaling factors in the system software since it is purely a function of the physical length and gauge of the wiring run.

The other components of the lead resistance problem are much harder to deal with. Since the resistance of most metals varies with temperature, (and therefore the metals are used to measure temperature) the resistance of the leads will vary with temperature. A variable error will be added or subtracted from the input resistance as the ambient temperature changes. In equipment rooms that see large temperature swings, several tenths of a degree to a degree or more of variability can be introduced into the measurement. The quality of the sensing connections is the third factor in the overall input resistance equation. Poor or loose connections will introduce inaccuracies that are difficult to predict, vary with temperature and degrade over time.

The following calculation illustrates the impact of lead resistance problems for a common sensing technology often applied without lead length compensation or a transmitter.

### Effect of length of lead wire on RTD measurements

- Distance to the sensor - 100 ft.
- Wire size - 22 AWG
- Specific resistance - 0.0165ohms per foot at 25°C
- Total lead length in series with the RTD – 200 ft.

The added resistance from the length of wire is 3.3 ohms. With an average RTF sensitivity of 4.7880 ohms per°C, the equivalent temperature associated with lead resistance is 1.24 °F.

### Effect of temperature change on RTD measurements on a rooftop unit where the conduit is run outdoors in the Midwest

- Minimum temperature - minus 20°F
- Maximum temperature - 105°F (assuming no solar effects)
- Temperature change - 125°F or 69°C
- Resistance temperature coefficient for copper - 0.0043 ohms per ohm per °C

For the temperature variability stated, the corresponding change in RTD resistance is 0.98 ohms. This change in resistance translates to a 0.37°F change in temperature due to the outdoor temperature.

### Overcoming Lead Wire Resistance

Two technologies help overcome susceptibility to lead wire resistance error. Lead length compensating wiring configurations can be used, or transmitters can be installed near the sensing element.

There are several lead length compensating wiring configurations, but three and four wire circuits are the most common. Four wire circuits provide the most accuracy. In general, these four wire circuits use one pair of wires to carry the current that excites the resistive sensor. This current creates the voltage drop that is measured by a high impedance voltage measuring device with the remaining two wires. The voltage measuring device accurately measures the voltage drop across the resistor without lead length effects because it draws very little current.

Another approach to minimizing the lead wire resistance effect is to use a transmitter. The transmitter converts the low level input into a higher level signal (1-5V, 2-10V, or 4-20 mA are common examples) and sends this signal to the controller. Even the highest quality transmitter will degrade the input signal to some extent, so a RTD with lead

### ***Lead Wire Resistance Error and Tight Specifications Don't Mix***

*The specification for an automation system that was intended to optimize the performance of multiple chiller plants on a one pipe chilled water loop called for 100Ω platinum RTDs installed for an overall accuracy of  $\pm 1/10^\circ\text{F}$  - a very tight spec that will not be achieved without a transmitter with a limited range or using lead length compensation. Instead of 100Ω platinum RTDs, 1000Ω copper RTDs without lead length compensation had been installed. The impact of the lead resistance made it impossible to meet the accuracy in the specifications by an order of magnitude. As a result, the system could not make the necessary temperature based decisions about starting and stopping the chillers on the one pipe chilled water loop making the system virtually useless in terms of its design intent.*

length compensation (4-wire RTD) can be more accurate than a transmitter if properly implemented.

### 3.3.2.2. Electrical Noise

**Voltage and current loops** A sensor measurement can be sent to the controller as a voltage or current loop. As the name implies, a current loop is simply an approach where the flow of current in a wiring circuit is varied in direct proportion to the measured variable. Current loops are often used since the signal is immune to both voltage spikes and degradation due to transmitting over a distance. As long as there is enough voltage available to drive the 4-20 ma signal through the total resistance of the circuit, then the wire can run as far as necessary. For example, a standard supply voltage of 24 vdc will drive 20 ma through a resistance of 1200 ohms.

Some transmitters require a separate power supply to drive their electronics and are commonly called four-wire transmitters (not to be confused with the 4-wire lead length compensation circuits described above). Others transmitters that simply take their power from the current loop itself are commonly called two-wire or self-powered transmitters.

Current loops use scaling resistors to generate a voltage signal at the controller. The scaling resistor at the controller accounts for either 250 or 500<sup>3</sup> ohms, which leaves 950 ohms for wires and transmitter electronics. The manner in which the current loop is terminated and the quality of the scaling resistor can impact measurement accuracy. Poor connections and low accuracy resistors will degrade signal quality. The biggest factor is the scaling resistor, which is predictable and controllable. A well done, secure connection will eliminate potential erratic problems. Many newer systems have the scaling resistors built directly into their circuit boards eliminating potential termination problems and locking down the quality of the scaling resistor to factory specifications. The scaling resistor installation is discussed in more detail under Section [3.3.4 Controller Error](#).

**Voltage Signal Interference** If a voltage signal is used instead of a current signal, the wire must be shielded to guard against voltage spikes and noise. Nearby cabling, conduit, or walkie-talkies can result in signal interference that reduces the accuracy of electronic measurements. Twisted shielded pair wiring (TSP) is made of two wires twisted and surrounded by a foil or braided metal shield. The twisted wires carry the signal from the sensing element to the controller. The shield prevents noise from external electromagnetic and electrostatic sources from affecting the signal on the twisted pair, while twisting the wires cancels out electromagnetic interactions between the pair of conductors that contribute to signal noise.

In connecting the shield to ground, the charges, voltages and eddy currents are dissipated. To aid in grounding the shield, a bare wire is wrapped into the shield and grounded. Since the shield is metallic, it has the potential to become a current carrying conductor itself. If this were to happen, then many of the benefits provided by the shield would be negated, and the shield itself could induce noise into the signal conductors. To prevent this conduction of current, the shield grounding wire must be grounded on only one end.

One of the functions of grounding is to establish a uniform voltage reference for setting voltage values in electrical circuits. In most buildings, this reference is established by

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<sup>3</sup> Based on Ohms law, a 250-ohm resistor will generate a 1-5 vdc signal with a 4-20 ma current flow. A 500-ohm resistor will generate a 2-10 vdc signal. Basically, this means that all systems ultimately work with voltage as the analog input measurement. Any system that can accept a voltage input can also accept a current loop input if care is taken with regard to the grounding of the input boards and the current loop power supplies relative to each other.

connecting the grounded conductors to the earth or ground (hence the name) or to conducting structures in contact with the earth (like water lines or building structural steel that has been connected to a buried grid of conductors). This reference is sometimes referred to as the grounding plane, and we tend to think that the ground reference voltage is equal at all points in the grounding plane. But in fact, the ground voltage is not always equal due to the resistance of the elements that comprise the grounding plane and variations in the resistivity of the soil. As a result, small differences in voltage exist at various points along the grounding plane. If a conductor connects these points, a small current will flow. The voltages that induce currents between points in the grounding plane are often called common mode voltages, and the problems that the currents create are often called common mode voltage problems.

Most electronics packages are designed to deal with common mode voltage problems and often contain a specification rating termed common mode rejection, usually expressed in terms of decibels or db. A higher rating is better than a lower rating. With current technology, there will seldom be a problem if the equipment has common mode rejection capability, the field wiring is shielded, and the shield grounding is handled correctly. When a problem does occur, it will typically occur on a very low level signaling system (milli-volt inputs from direct wired RTDs for example) or on the communications wiring on a network.

**RTDs and Noise** Of all the inputs commonly found on HVAC systems, RTDs are probably the most subject to noise problems. Generally, this is because of their low resistance change per unit temperature change (fractions of an ohm per degree) and the millivolt signals associated with the bridge systems used to read them. In theory, these issues can be handled with proper shielding techniques, which is not as easy as it sounds in a real construction environment because incorrect shielding techniques are difficult to track down. Adding a transmitter to an RTD solves both problems with lead length resistance noise, especially if a current loop is used.

### 3.3.3. Transmitter Error

Limiting transmitter span is a technique that can be used to provide greater measurement resolution and accuracy. For example, a 12-bit A to D converter at the controller resolves an input into 4,096 counts ( $2^{12}$ ), so the 16 ma span of a 4-20 ma transmitter is divided into 4,096 units. If the 4-20 ma signal represents a temperature change (span) of 100°F, then the transmitter can break the 100°F down into 4,096 parts so that each count represents 0.024°F. The temperature cannot necessarily be read to  $\pm 0.024^\circ\text{F}$  accuracy for other reasons like repeatability, hysteresis, drift, and sensor self heating, but the signal that is received can be broken down into an identifiable part that is that small. If the span is reduced to 50°F, each of the 4,096 counts represents a smaller increment, and in this case the resolution is 0.012°F per count.

### 3.3.4. Controller Error

A number of measurement errors can occur at the controller due to incorrect scaling parameters, limited analog to digital converter resolution, problems with scaling resistors, and the controller's change of value limit setting. The description of the controller software, firmware and hardware in the sidebar give background for this discussion of controller errors.

#### 3.3.4.1. Scaling parameters

The scaling parameters for each point must be correctly set in the DDC software at the controller. This information is usually entered as configuration information for the point database when the controller is set up, a function that is independent of developing the software code that executes the control strategy for the system. In some systems, the scaling parameters for a temperature measurement using a 4-20 ma signal can be set directly as ; i.e. 4 ma = 20°F and 20 ma = 200°F. In other systems, these

#### **Hardware, Firmware, and Software – What's the difference?**

*DDC controllers have several terms that are used to reference their physical and non-physical components. The controller's hardware is the physical component of the controller including items like its circuit boards and terminal strips. The programming placed in a DDC controller is referred to as the controller's software. The software actually has two fundamental components, the point database and the operating logic. Both components are typically stored in the controller's programmable memory to allow them to be custom configured to the needs of the system. The point database contains defining information about the physical points that are wired to the controller's terminal strips as well as the virtual points that it uses to calculate and store information. The point definitions typically include information about the type of point, scaling factors, name, descriptor, engineering units, alarm states, and the physical terminals or memory location associated with it. The operating logic software tells the controller what to do with the points defined by the point database. The controller's firmware is what ties the operating logic and point database together with the controller's microprocessor. Essentially, it is the operating system of the controller. The firmware is typically stored in programmable read-only memory, which can be modified by the factory to add improvements or fix bugs but cannot be modified by routine programming commands in the field. (continued on the next page)*

scaling parameters are based on the span set at the sensor or transmitter.

### 3.3.4.2. A to D Converter Resolution

After the controller receives an analog signal from a sensor, the signal must be converted from analog to digital for use in the controller microprocessor. The resolution of A/D converters is a result of the resolution (8-bit, 12-bit, etc.). As stated in the discussion of limiting the transmitter span, a 12-bit A/D converter can resolve a measurement span into 4096 increments. An 8-bit resolution resolves into 256 ( $2^8$ ) increments. If the resolution is too low, then the analog sensor reading will be degraded, since the step values in the measurement will be too large.

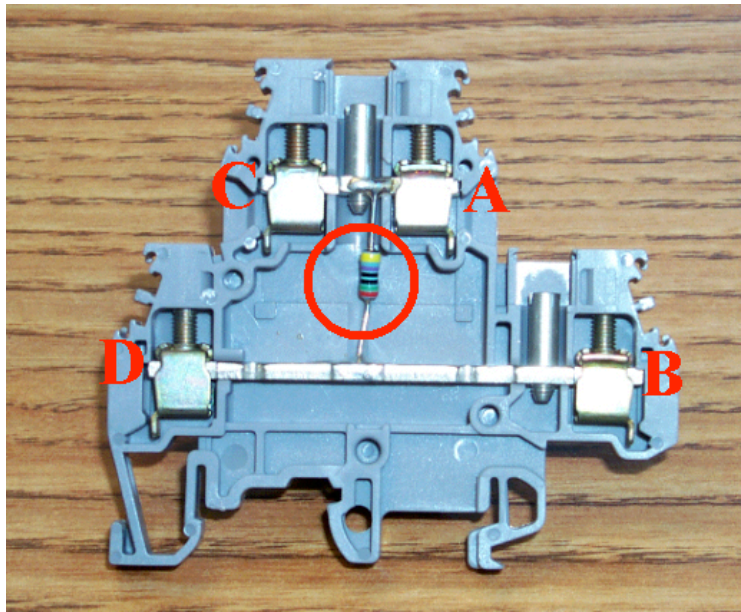
### 3.3.4.3. Scaling resistors

Current loops use scaling resistors to generate a voltage signal at the controller. If the scaling resistor is not already incorporated into the controller circuit board, it is necessary to add high precision scaling resistors in the field.

Typically, this scaling resistor is mounted under the same terminal as the twisted shielded pair that is bringing the field signal into the controller. When the solid resistor lead is clamped under the same terminal screw as the stranded field wiring, the clamping action on the stranded field wiring is limited. Over time, the scaling resistor ends up looking like a loose electrical connection and the resistance changes. While this resistance change is not large, the voltage drop it produces is erratic and also significant in magnitude relative to variations in voltage drop that occur at the precision resistor as it converts current changes representing fractions of a degree to voltage. As a result, a variable and unpredictable calibration error is introduced into the system.

*(Continued from previous page)*

*Due to memory limitations, some systems store part of the point database information and non-critical programming information at a location other than the controller. In these situations, the controller memory will contain critical information required to execute the program such as the program itself and fundamental point database information. Other information like the point descriptors, comment lines, and other parameters that are not essential to run the program are stored in other devices. This non-essential information is commonly located in the network supervisory controllers or on the host computer's hard disk. This information is put together so that someone looking at the system through the operators console window can view it seamlessly. But, if a programming tool were attached to the controller itself, all of the information may not be available, depending on where it was stored.*



**Figure 3.1 Resistor Terminal Block**

The resistor is circled in red and brazed between the two bus bars (top and bottom). To use it, you wire the current loop so that it flows through the resistor from A to B, and then pick up the voltage drop and take it into the system I/O at C and D.

Fortunately, there are specialized terminal blocks that are made to handle this problem. One such terminal block is illustrated in Figure 3.1. The blocks consist of double deck terminals with a precision resistor soldered between the upper and lower deck. The current loop flows through on one side and the voltage across the resistor can be picked up on the other side. Several firms manufacture these terminal blocks with resistors sized for the two most common standards (250 and 500 $\Omega$  high precision). Other resistance values can be special ordered.<sup>4</sup>

Terminal strips and some of the special features that can be built into them can also:

- Make troubleshooting easier at the controller by allowing the field wiring to be isolated from the controller without lifting wires via a simple, built in switch mechanism
- Allow standard troubleshooting techniques to be developed that allow operating staff with less experience to diagnose and correct field sensor problems.
- Provide a consistent and accessible point of identification for the numerous wires associated with the control system.
- Make future controller upgrades and replacements simpler and faster to accomplish.
- Serve as boundary between sensor installation and panel control responsibility.

<sup>4</sup> From a commissioning and operations perspective, these terminals also eliminate that annoying little clink sound that you hear right after you loosened up a connection on a controller, not realizing that there was a precision resistor clamped under it. The sound was the resistor falling into something in the panel. Locating a supplier for one precision resistor to replace the one that was lost can be difficult, especially on projects in remote locations.

These features are discussed in greater detail in *Chapter 2: Control System Design Process*, Section [2.3.5](#).

### 3.3.4.4. Controller change of value limit

The I/O microprocessors in a controller scan the data from its inputs, put the data into memory, and execute programming code using the data. Change of value (COV) limits are often set to control two areas:

- How much change in the measured value must occur for the controller to process the input values in the programming code.
- How much change in the I/O points must occur for the controller to send information over the network to the workstation.

If the change of limit parameter is too low, point fluttering will result in many small changes in output and many updates to the central workstation – this high traffic can cause the network to crash. Filtering techniques can also help reduce this occurrence. If the COV limit is set high, the controller may not have good control response to the sensed inputs or the workstation will not be updated with the measured values that the controller is acting upon. It is important to keep in mind that the microprocessor may be working with a different number than what is seen at the workstation screen.

For example, if the COV limit for the network to sense a change is 1 degree and the COV limit for the microprocessor to execute the programming code is 0.1 degree, then the microprocessor could be controlling to a tighter degree than is seen at the workstation. This is especially problematic when tuning control loops, since the workstation may not be displaying the true system response. When a step change is introduced into the control system, a large COV limit for the network makes it easy for the technician to think that the system is sluggish and needs to have its tuning parameters adjusted. The loop may actually be hunting, but the magnitude of the hunt is smaller than the network COV limit, so it is not visible at the workstation. As a result, the technician may overreact and begin to modify the tuning parameters to make the loop more sensitive, which only makes the problem worse and can lead to another problem called wind-up. (See the Functional Testing Guide, [Overview and Applications of PID Control](#) for a description of wind-up). As a general rule, a stepped, square-wave system response curve viewed at the operator's workstation is a good indicator of a large network COV limit, especially if the step changes are uniform in magnitude.

### 3.3.4.5. Software version

Without careful management of the system's software, it would be quite easy for a working program to be replaced with previous version of the program. This overwriting could even occur automatically, triggered by a controller recovering from a power failure and downloading bad information. As a result, a well-tuned system can suddenly have problems.

As good operating practice, it is important to make sure that any modifications made to a controller's software are saved and backed up appropriately. Different systems handle on-line program editing in different ways. In most cases, there will be at least two locations where the program data is stored. One is in the controller, where the program is actually running. The other is on the hard disk of the operator's workstation, where a copy of the program (or some version of the program) usually resides. Additional copies of the program or edited versions of it may also exist on the laptops of the control technicians working on the system and on back-up tapes and CDs. The back-up method

used should provide a standard method for saving versions of the software. These procedures can be addressed during operator training and through documentation to minimize the possibility for corrupting the system's software by overwriting the latest version of the software with an older, incorrect version (see the sidebar below).

### 3.3.5. Network Architecture Effects

Designers should keep network architecture limitations in mind when designing control systems so that the network does not adversely affect control functions. The way the network packages data for transmission affects the data seen at the workstation. The design of network communications can severely limit the frequency that data is updated at the operator's workstation as well as increase the control loop response times. These effects, while not errors in the purest sense of the word, can cause data to be misinterpreted.

While a properly implemented control loop should not be configured to run over the network and thus will be immune to the direct effects of slow network communications (see Section [3.2 Point Selection](#), recommendation #3), the ability to tune the loop based on the observed performance at the operating console can be severely limited by slow data handling. The functionality of the control system graphics and the ability of the operators to command and control the system manually, especially in an emergency, can also be compromised by poor network functionality.

Commissioning providers need to be aware that when tuning a loop or observing the performance of a system, there may appear to be delays in the system's response due to data handling problems if there are many controllers on a lower speed network. These delays may not actually exist at the controller making the system more responsive than it appears. These delays are a result of the network architecture, with controllers either residing on a network with peer-to-peer communications or on a lower

#### ***Replacing the Good with the Bad:***

*Some systems allow the technicians to edit a copy of a program or point database and then download the modified software to the controller, overwriting the existing software with the new information. In this situation, the possibility exists for an existing, working program or error free database to be overwritten by a modified program or database with a bug or error in it if the starting point for the modification was not a copy of the working program. Even if the modification used the working program as a starting point, it is possible that the modification may turn out to be a bad idea and having a copy of the working program available to revert to (quickly) may be highly desirable. Other systems allow programs to be modified "on the fly". In this case modifications made to a controller's software to debug it or calibrate a point, will not be reflected on the copy saved at the hard disk unless the modifications are uploaded after they are made. Usually this must be manually initiated. If proper back-ups are not maintained then the "good" software residing in the controller may be lost if the controller's memory is cleared by some event (like a power failure). Or the "good" software may be accidentally over-written by an older version accidentally downloaded from the disk, either by an operator error or an automatic download triggered by some system event.*

speed network with supervisory (or global) control modules polling the controllers. Section [2.3.3.2 Component Specifications: Controllers and Actuators](#) includes a detailed discussion of network communications.

### 3.3.6. Workstation Effects

Other opportunities for error beyond the controllers exist – the data that is shown on the workstation graphics may not be the same data that the controller sees. When troubleshooting a questionable reading at the workstation, it may be necessary to check the measurement directly at the controller using a laptop. As long as the microprocessor in the controller is getting good data from the input devices, then it can control well. If the data is not properly conveyed to the workstation, then it may not be apparent that the controller is working.

### 3.3.7. Installation Errors

A temperature sensor located near a diffuser or computer monitor, or an outdoor air temperature sensor that is not properly shielded from solar radiation can be large and highly variable sources of error. Outdoor air temperature sensors can also be affected by exhaust air. Locating a sensor on the wrong branch of a pipe or duct tee can totally change the data that it is reporting.

Placing sensors in the appropriate location can be difficult. It is not uncommon for the installing tradesmen to misinterpret the location of a sensor shown on a schematic or described only by a note. Showing the sensors on floor plans can help, but floor plans are still a two-dimensional picture, and some interpretation of exactly where the sensor goes is required. Often inches can mean the difference between being in the right spot and being in the wrong spot. An effective way to minimize this problem during the construction process is to locate the sensors during a walk-through of the project conducted after the systems in which they will be installed are in place. The exact location can be marked on the piping and ducts with indelible markers using the point symbol and point number. This approach provides benefits to all parties involved in the process:

- **The Designer** is provided with the chance to be sure that the sensor is installed exactly where it needs to be in order for the design intent of the project to be achieved.
- **The Owner and their Operating Staff** are exposed to the location and installation requirements of the sensors controlling the systems they will be charged with operating

***The Coffee's Hot, but the Break Room is Freezing:*** On one project, the operating staff of a new facility who had yet to receive control system training were plagued with cold complaints from the break room, which seemed to be caused by a major calibration problem with the input sensor. Unfortunately, they could not find the sensor since it was not shown on the plans and the location did not seem obvious when they inspected the space. The "light came on" several weeks later during the control system training when the trainer projected a picture of the temperature sensors used on the project up on the training screen. The sensors were designed in an architecturally pleasing package that looked just like the blank cover plate used to close off an unused electrical device opening in a wall. Just such a cover had been noticed in the troublesome break room, directly behind the large coffee maker. The next day, relocating the coffee maker solved the break room temperature control problems.

and maintaining. This can be a valuable training lesson and also can provide insight into the design intent behind some of the sensor requirements.

- **The Control Contractor and the Installing Tradesmen** have the opportunity to review the sensor location in the context of the surrounding systems as well as the physical arrangement of the system the sensor is installed in with the designer present. Design and contractual issues that may not be obvious in plan or schematic can be identified, discussed and resolved on the spot in an interactive environment involving all concerned parties in the process.

Along these same lines, during start-up, it may be advisable to go look at a sensor that is providing what appears to be inaccurate questionable data. You may discover that it is in the wrong place and is actually providing the system with very accurate but inappropriate information.

The bottom line in the commissioning and operating arena is to remember that what is happening at a sensor in the field is not necessarily the same as what you see on the workstation. Understanding the different opportunities for error from the sensor to the workstation allows a commissioning provider to anticipate and troubleshoot these problems in the field.

### 3.3.8. Persistence of Accuracy

Checking that the calibration is within a tolerance and the signal is correctly displayed at the workstation should be a part of a regular maintenance routine. New sensors and transmitters will degrade over time due to factors such as thermal drift, mounting effects, vibration effects, and aging of components. The decay is usually a function of the quality of the transmitter. For a given accuracy, more expensive sensors have higher quality housing construction (i.e., utility box housing vs. explosion proof) and long-term stability of the electronics. Long-term stability and low thermal drift may not be an issue for a space temperature sensor, but it could be absolutely critical for a chilled water sensor, especially if the sensor is used for load calculations by a load-based control algorithm.

A number of persistence issues are described below.

- Some sensors can be sensitive to the location and manner of installation. As a result of mounting effects, a sensor calibrated for one location will not necessarily remain calibrated if it is moved to another location or if it is installed in a different orientation from that which it was factory calibrated.
- The connection of the twisted shielded pair to the controller can degrade over time, with resistance developing where the stranded wire (twisted pair) is clamped to the scaling resistor lead. The added resistance results in large errors in measurement. See [Section 3.3.4 Controller Error](#) for more details.

## 3.4. Installation Guidelines

The following section presents guidelines for installation of monitoring and control devices. Installation details for all safety points are critical to safe operation of the building's systems. Calibration test ports and techniques are emphasized since careful calibration is essential for proper control.

### 3.4.1. Safety Points

Three general guidelines apply to all safety interlock points.

- 1 Safety points should be hardwired to the system they serve to shut down the air handling unit regardless of the operating status of the computer system, its network, or the position of the starter or VFD selector switches (Hand or Auto - Local or Remote - Inverter or Bypass).** The control system software should not be relied upon to perform critical safety operations, since the software will not shut down the system if the fan starter, output circuit board, or drive selector switches are placed in the hand or bypass positions.
- 2 The input to the safety circuit should be a different sensor than the input to the control loop.** Otherwise, the “fox is guarding the hen house” since the sensor tries to protect the system from a problem that could be caused by its own failure. For instance, an independent freezestat should be provided even if the air handling system has a mixed air temperature controller or sensor. The independent freezestat provides a valuable “second opinion.” A number of potential problems ranging from calibration to computer failures could make the DDC mixed air sensor unavailable or unusable for safety purposes. In addition, the independent devices used for safety controls are by design, fairly simple and rugged pieces of hardware that are immune to programming errors, microprocessor failures, and network communications problems.
- 3 The safety device should require a manual reset to allow the system to resume normal operation.** Making the safety device a manual reset type of switch forces a manual intervention to allow the system to resume normal operation. Hopefully, the person resetting the system will first investigate the cause of the safety trip and correct it before resetting the switch. This is an important training issue and a good target for an operating procedure for owners who use written procedures to direct operators in various situations.
- 4 Failure modes need to return dampers and valves to safe positions.** Hardwired interlock switches piloted by the proof of operation circuit should be provided to return critical dampers and valves to a normal, fail-safe position when the system is not operating. This is important because the system could be shut down by functions outside of the DDC controller, including manual intervention at the starter by selecting “Off” on the selector switch, belt or drive coupling failures, or undetected localized power outages. Items to consider include:
  - Failure to close these outdoor air or relief dampers when the unit was off could cause a coil or plumbing in the building to freeze during cold weather. During warm weather, the open dampers could allow the building to fill with hot, humid air, creating a potential condensation and pull down load problem at restart.
  - Failure to close the chilled water valve on inactive units can waste pumping energy at the central plant if it remains in operation to serve other loads. Leaving the valves open can also cause performance problems with variable flow central plants since the inactive coil with an open control valve creates a hydraulic short circuit that

depresses the return temperature while creating a flow condition associated with a high load conditions. On some systems, the wide open valve may cause condensation problems because the stagnant air in the vicinity of the coil will be cooled to very near the chilled water supply temperature rather than the chilled water return temperature, which locally lowers the dew point of the air and the temperature of nearby surfaces below the surrounding dew point.

Description of the operation and guidelines for the application of the following typical safety points are included in the following sections.

- [Freezestat](#)
- [High static pressure switch](#)
- [Proof of Operation Interlocks](#)
- [Air flow switch](#)
- [High temperature limit control](#)
- [Smoke detector](#)
- [Firestat](#)
- [Position and limit switch](#)
- [Multi-Speed Motor Interlocks](#)
- [Variable speed drive programming](#)
- [Motor Overloads](#)

### **3.4.1.1. Freezestat**

The freezestat protects coils from freezing when cold outdoor air enters the mixing box by providing an input that is interlocked to shut down fans, close outside intake dampers, and open heating coil valves. For mixed air applications, freezestats on the entering side of the heating coil and monitoring the heating coil return water temperature may be necessary to fully protect the system, since a reduction in return water temperature occurs and can be detected faster than the air temperature drop. To attempt to avoid the system outage from a freezestat trip, the DDC system can generate a warning alarm ahead of a system shut down by the freezestat.

The freezestat elements should be tie-wrapped with the DDC mixed air temperature sensor element. For large systems, more than one freezestat and more than one mixed air sensor may be required to adequately cover the plenum. A good rule of thumb is to provide 1 foot of element for every 4 square feet of coil face area. In this way, the DDC system and the freezestat see the same temperature. Remember that freezestat elements may look like averaging elements, but they do not average; rather, they are designed to respond to the lowest temperature seen by a specific length of the overall element.

See Section [5.6.3.2](#) Freezestats in the Functional Testing Guide for a detailed description of operation.

### **3.4.1.2. High static pressure switch**

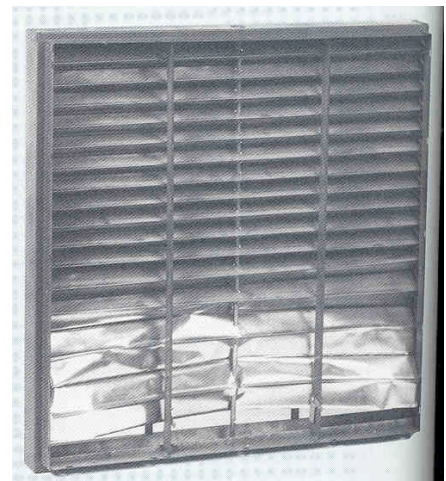
A supply air duct high static pressure switch set at the duct pressure class rating shuts down and locks out fans to protect the air distribution system from excessive pressures that could damage ducts. This type of switch will protect the equipment from a relatively gradual over-pressurization or continued operation at an over-pressurized condition. This

over-pressurization is created by a restriction in airflow that pushes the fan up its operating curve, where the peak on the operating curve is higher than the rated static pressure of the duct system. An example of a situation where a high static pressure switch might be desirable would be a large system that was equipped with smoke isolation dampers in which the potential exists for the fan to start with the isolation dampers closed.

High static pressure switches **will not** protect a system from the effects of air hammer that can occur when fire dampers or smoke isolation dampers close suddenly with the system in operation. A fan that is moving approximately 25,000 cfm is literally moving a ton (2,000 pounds) of air a minute. For a detailed description of how to protect a design against air hammer, refer to see *Chapter 13: Supplemental Information*, Section [13.5.3: Air Hammer](#).

### 3.4.1.3. Proof of Operation Interlocks

The supply fan proof of operation interlock should be used to pilot hardwired interlocks to close critical valves and dampers. Interlocks should be provided for the outdoor air damper, relief damper, smoke isolation dampers, minimum outdoor air constant volume regulators, and the chilled water valve when the fan is not in operation. These hardwired interlocks are in addition to providing proof of operation indication to the DDC system. This interlock should function regardless of the state of the DDC system or any selector switches controlling the fan and should be totally independent of the DDC system software.



**Figure 3.2 Duct and Damper Damage due to Air Hammer**

(Image courtesy of the Ruskin Catalogue)

### 3.4.1.4. Air flow switch

Air flow switches are typically provided with electric reheat coils to shut them down upon loss of air flow to protect the coils from overheating and causing a fire. The National Electric Code requires them along with temperature based limit controls, some of which may require a manual reset when tripped. The air flow switches are usually differential pressure switches arranged to sense the velocity pressure entering the coil.

### 3.4.1.5. High temperature limit control

High temperature limit controls shut down electric reheat coils if the coil casing temperature exceeds the setpoint. The National Electric Code also requires these devices. Only automatic reset limit switches will typically be installed on smaller (in terms of kW rating, not face area) coils. Larger coils will have an additional limit control that must be manually reset if it is tripped.

### 3.4.1.6. Smoke detector

Smoke detectors are typically installed in the supply and return air streams to the air handling unit and at smoke separations. They can be hardwired to shut down fans, shut smoke dampers, and perform other fire and smoke management functions directly. However, they are often wired to signal the fire alarm system, and the fire alarm system sends commands to the appropriate dampers and motor control circuits.

There are several important points to remember with regard to smoke detectors in addition to the points already made about safety devices.

- 1** Because the smoke detectors are often a part of the fire alarm system that is installed in the HVAC duct system and interfaced to by the control system, they require a coordinated effort on the part of several specification sections and trades in order to provide a complete and functioning installation. The designer can arrange their specifications and drawings to make the coordination requirements clear to all parties and define key requirements and responsibilities.
- 2** Duct mounted smoke detectors usually have sensing tubes that extend into the duct system into the detector, which is typically located in a housing on the outside of the duct. Specific requirements apply to the position, length, and orientation of the sensing tubes in the duct system that must be met in order to ensure the correct operation of the detector and maintain its U.L. listing. These requirements are specific to each manufacturer's equipment. Thus, while the sensing tubes from Manufacturer A's detector may physically fit into Manufacturer B's detector, they probably cannot be substituted for Manufacturer B's sensing tubes without violating Manufacturer B's U.L. listing. Similarly, in most instances, the sensing tubes cannot be field cut to make a tube fit an existing condition without violating the U.L. listing of the detector.
- 3** Very large ducts may require extra detectors to adequately protect them. Local code officials may require this even if there is no specific language in the applicable building code regarding detector requirements as a function of cross sectional area. It is usually a good idea to meet with the local code official sometime during the design process to review issues like this. Most officials will welcome the opportunity to influence the project in the early stages rather than having to fight to get a change made during the final stages of construction. Arranging for such a meeting lets the code official know that the designer is aware of their needs and requirements and can pave the way for a good working relationship throughout the project.

### 3.4.1.7. Firestat

Firestats are manual reset high temperature limit devices required by code in smaller air handling systems where smoke dampers are not required and in exhaust systems. Generally, firestats are not as common as they were at one time since smoke detectors can provide the required protection along with other features needed for code compliance on a project.

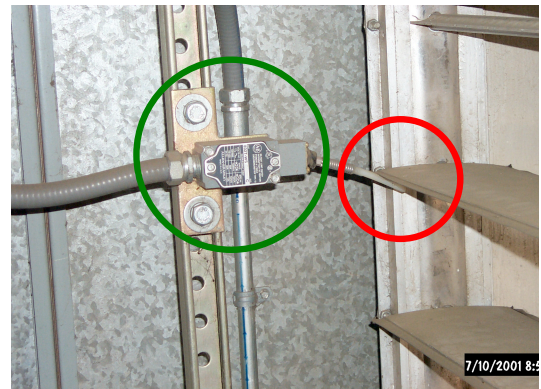
### 3.4.1.8. Position and limit switch

Fire and smoke dampers are often equipped with limit switches to monitor and indicate blade position. Back draft dampers on exhaust fans and parallel fans are often equipped with limit switches, as well as intake dampers on 100% outdoor air systems. Generally, the limit switches will be two position switches that indicate that the damper is either open or closed. However, it is also possible to obtain analog switches that provide an output that is proportional to the rotation of the damper blade if this type of information is required by the control system or the smoke management system.

Many buildings incorporate fire and smoke management systems that require that a panel be provided to allow a fireman to monitor and manually control the various smoke dampers and fans in the building in a fire situation. Usually this requirement is driven by code requirements, but it can also be driven by an owner's own internal requirements or by the owner's insurance underwriter's requirements. To convey damper position information, systems of this type use the damper position switches for an indicating circuit to light pilot lights at a fireman's control panel. In most cases, factory installed limit switches provided with the damper will provide adequate service for this type of application.

The damper position and limit switches can also be used to provide a permissive interlock that will not allow or "permit" the fan system to operate until key dampers are in safe positions. These switches will ensure that fan operation does not over or under pressurize the ductwork due to restricted air flow. While factory-installed switches can be used for this function, they often lack the precision and adjustability required to provide the best level of protection and adjust the trip point of the switch to the operating requirements of the system. Some issues to consider when selecting and applying limit switches include:

- Arrange the switch to sense blade position, not linkage or shaft position. Shafts and linkages can come loose from the blades they drive.
- Multiple section dampers may require multiple limit switches. In general, the goal should be to prove that enough of the damper assembly is open to allow the fan to move the design flow of air without collapsing the intake system or blowing apart the discharge system.
- The switch mounting arrangement should hold the switch securely, but allow it to be easily adjusted vertically and horizontally to fine tune the point at which it trips. Unistrut™ and similar steel channel type framing systems are provide a variety of options for achieving this using standard fittings and clamping bolts that slide inside of C channels. (see Figure 3.4).



**Figure 3.3 Limit Switch Installation for a Permissive Interlock**

This standard motion control switch's sensing arm has been adjusted to respond to blade rotation (red circle). Note also how the Unistrut™ mounting support arrangement coupled with the flexible conduit connection (green circle) will allow the switch to be easily shifted up and down and in and out to fine tune the trip point.

- The limit switch should be adjusted so that it does not sense that the damper is open until the damper is truly open. In addition, the differential should be tight enough that, on the return stroke, the switch indicates that the damper is no longer safely open at nearly the same point. When the damper is commanded open, the switch should be adjusted so that it does not indicate that a fan start would be safe until the damper is open far enough that the pressure drop through it with design flow would not create an unsafe pressure downstream of the damper. Typically, this will be at 85° or more of blade rotation. Similarly, when the damper starts to close, the switch should open and indicate that the damper is no longer safely open at nearly the same point, in the case of this example, 85° of blade rotation. Obviously, any real switch will have some hysteresis and switching differential, so the make and break points will not be identical. Lower quality switches often have wider switching differentials and more hysteresis than higher quality switches.

Additional information regarding this type of interlock that is peculiar to economizers can be found in the Functional Testing Guide, [Section 5.5: Operational Interlocks](#).

### 3.4.1.9. Multi-Speed Motor Interlocks

While variable speed drives are being used for many applications previously served by multi-speed air handling equipment, multi-speed motors are still used on projects where only two distinct operating points are required, and where the complexity associated with a VFD is not desired by the Owner. Multi-speed motors require some special interlocks above and beyond those provided as standard for a typical motor interlock circuit to protect the motor and equipment. Generally, there are three areas of concern:

- 1 The interlocks must be arranged to prevent the high-speed motor winding from being engaged or energized at the same time as the low speed motor winding.

To provide two-speed control with a DDC system, it is typically necessary to have two outputs. There are several ways to use these outputs to produce the speed change. The manner in which the outputs are implemented can enhance the interlocking safety designed to protect the system from simultaneously energizing both motor windings. The most obvious approach is to use one command to control the high-speed starter coil and one command to control the low-speed starter coil. This approach allows the system's software to be used to provide the speed command.

Using a relay with a Form C contact (Figure 3.4) to perform the speed change command can provide an added measure of safety because the physical arrangement of the contact makes it virtually impossible to have both the normally open and the normally closed terminals energized at the same time.

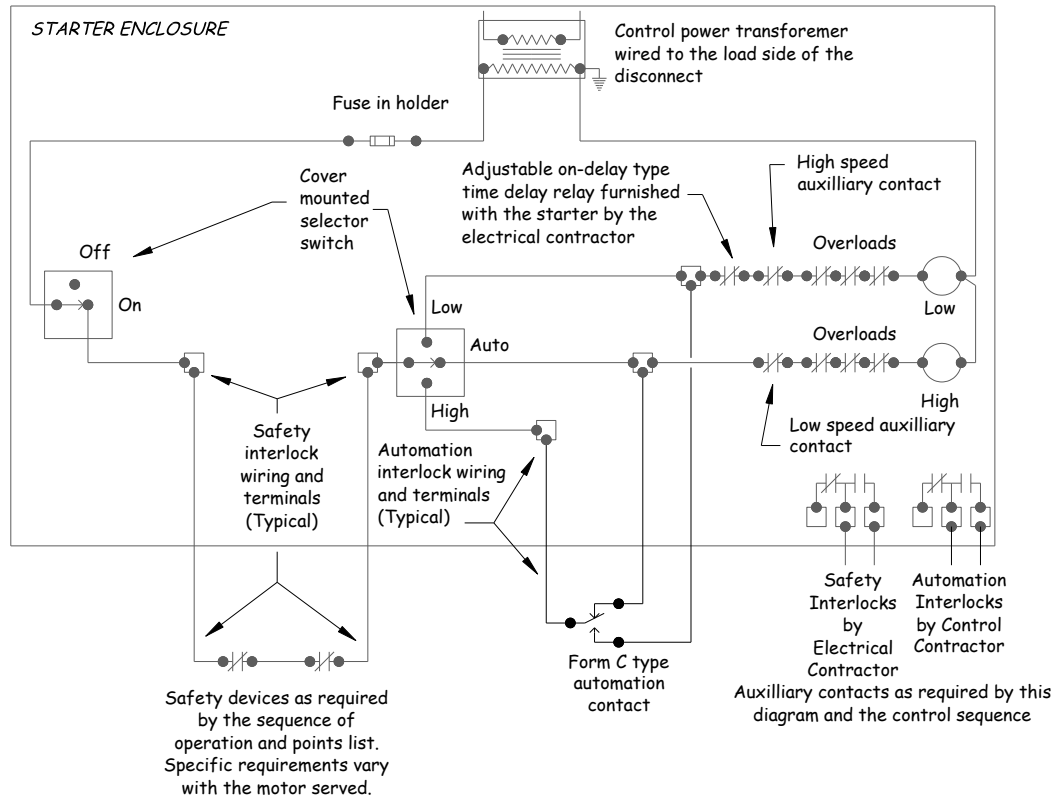
Regardless of how the control system command points are arranged, an additional hardwired interlock should be provided in the starter as a final measure of insurance against simultaneous energizing of the high and low speed windings. This interlock can be accomplished by wiring a normally closed auxiliary contact<sup>5</sup> from the high-speed motor starter in series with the low-speed motor starter. While somewhat redundant with the interlocking features described in the preceding paragraphs, this hardwired interlock provides added insurance in the event of a manual override of the control logic at the starter selector switches for little additional cost.

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<sup>5</sup> Auxiliary contacts are electrical contacts that change state any time the starter coil changes state. For instance, a normally closed auxiliary contact will be closed with the starter coil is de-energized, and open when the starter coil is energized.

- 2** All other safety interlocks must be arranged to shut down the motor and machinery regardless of which motor speed is active and regardless of the position of any selector switches.
- 3** The interlocks need to be arranged to protect the drive system that transmits the power from the motor to the driven machinery. There are two components to this.
  - a) Some drive systems have minimum speeds that they must operate at or above to ensure proper lubrication of all the internal components (gear boxes are typical of this). This is a design requirement that is often addressed by the equipment supplier in a manner that is nearly transparent to the designer. But for an equipment substitution or a repair to an existing system, this area can become a commissioning issue.
  - b) When the motor changes to a lower speed, the utility system imposes a significant and nearly instantaneous braking effect on the rotating fan wheel, drive system, and rotor. This nearly instantaneous change in speed and dissipation of energy places a huge stress on the drive train components and can destroy gearboxes, shear shafts, and keys and cause belts to be thrown. This problem can be averted by providing a time delay in the control logic to delay energizing the low speed winding for an interval of time after the high speed winding are de-energized. The delay should be long enough to allow the air movement loads on the fan wheel and drive and bearing friction to slow the wheel down to a speed at or below that associated with low speed operation so that when the low speed windings are energized the fan is already running at the lower speed or requires a slight acceleration to bring it up to the lower speed. It is tempting to simply use the DDC programming capabilities to provide the time delays and eliminate an independent time delay relay from the control circuit. This approach should be used with caution because if someone elected to manually make the speed change, they could damage the drive system if they did not wait for a sufficient interval of time between de-energizing the high-speed windings and energizing the low speed windings.

Figure 3.4 illustrates a typical multi-speed motor interlock circuit and illustrates some of the concepts discussed in the preceding paragraphs.



## TYPICAL TWO SPEED MOTOR INTERLOCK WIRING

### NOTES:

1. This drawing shows general interlock requirements for two speed motors. See the specifications, point list, and sequence of operations for specific safety interlock and automation requirements for individual motors.
2. All control devices external to the starter shall be furnished by the control contractor. Wiring between the safety interlock terminals shall be by the electrical contractor. Wiring between the automation terminals shall be by the control contractor.
3. The electrical contractor shall be responsible for the operational integrity of the control circuit in any of the manually selected modes (On, Off, Low, High).
4. The control contractor shall be responsible for the operational integrity of the control circuit in the Auto mode and for the operational integrity of all control devices they furnish, regardless of who mounts and wires them.

**Figure 3.4 Typical Multi-speed Motor Interlocks**

AutoCAD users can double click to open the image.

### 3.4.1.10. Variable speed drive programming

Most current technology variable speed drives incorporate microprocessors that allow them to perform a wide variety of functions that can be used to tailor their application. There are some parameters related to the safety of the drive that are usually arranged to prevent them from being placed in a state that would jeopardize the drive. Other parameters pose no threat to the drive in any of the possible states, but could pose a threat to the HVAC system or the loads served by them if not properly programmed. In some ways, this programming is more of a commissioning issue than a design issue but designers need to include provisions in their drive specifications for drive start-up, programming, and training by a person knowledgeable with all aspects of the drives. It is

helpful to include a list of HVAC-oriented requirements that relate to typical drive parameters to guide this process.

Many designers simply specify a factory start-up of the drive. This is highly desirable, but if it is not provided, then someone familiar with the drive should be required to perform the following work at a minimum.

- **Disable VFD capability to function regardless of the status of the external safety devices and interlocks wired to its input terminals:** The design of some drives allows the drive to be placed in a local control mode that will cause the drive to ignore all external safeties and interlocks, regardless of their status. While useful in the process industry, this feature has the potential for disaster in HVAC because it can easily be misinterpreted by the operators, who think they are simply taking control of the start-stop function when in fact they have also taken away any safety functions. Most drives with this feature have a programming parameter that allows it to be disabled so that an operator cannot place the drive in the external safety override mode.
- **Enable and Properly Set the DC Injection Braking Parameters:** Most current technology drives have the capability to perform a braking function by injecting a DC signal onto the motor power circuit. The stationary field created by this DC signal can bring a rotating motor to a stop much more quickly than would occur if it were simply allowed to coast to a stop. It can also stop a motor that is spinning backwards. This feature can be particularly useful in HVAC. A spinning fan connected to a de-energized motor is putting energy into the motor shaft causing the motor to actually function as an unregulated generator. If the variable speed drive is engaged against this unregulated voltage source, the voltages and currents created can damage the drive circuitry. Programming the DC injection braking to bring the motor to a complete stop prior to starting and accelerating it can protect the drive from damage.
- **Coordinate with the Control Contractor and Commissioning Team to Adjust Drive Parameters During Start-Up:** Drives have many adjustable parameters that can be modified to match the unit to the requirements of the system. Some of the more crucial parameters related to the voltage and motor characteristics are typically factory set. Others must be configured in the field to tune the drive to the system. For HVAC systems, the key field-tuned parameters typically include:
  - Acceleration and deceleration settings.
  - Minimum and maximum speed settings.
  - PID loop parameters if an on-board PID loop has been provided and is being used for control.
  - Communications settings if the drive is being networked with the automation system via a communications bus.
  - Programmable input and output functions.<sup>6</sup>
  - Input scaling factors.

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<sup>6</sup> Many current technology drives have programmable inputs and outputs that can be used to provide hard wired information to a non-networked system. The information that can be provided is generally any of the information available at the drive microprocessor. Common HVAC selections include drive operating status, drive output frequency, motor kW, drive safety status, and motor amps.

### 3.4.1.11. Motor Overloads

The National Electric Code requires motor overload protection for all motors. Smaller motors (fractional horsepower, single phase) provide this protection via internal sensors that simply shut down the motor if it gets too hot. Larger motors typically require independent components external to the motor to serve this function, typically mounted in the starter or drive. Motor overloads can be electro-mechanical or solid state but the primary function is still the same: to shut down the motor if it is operating under a sustained overload condition. The overload condition is different from a short circuit condition. Short circuit protection is provided by other components in the motor power circuit, usually the fuse or circuit breaker. Overloads typically must be adjusted to match the motor nameplate amps and service factor rating so that the motor is shut down if the load on exceeds its rating. When properly sized and selected, they can also provide a measure of protection against “single phasing”, the situation that occurs when a motor experiences a power loss on only one phase. When this happens, the motor will generally continue running but will rapidly overheat. Properly sized overloads can detect this condition and shut down the motor to protect it from damage.

### 3.4.2. Manual Override

The owner may desire a simple way for the zone occupants to override the operating schedule regardless of whether or not a facility operator is on site. The manual override can be accomplished via a variety of techniques including:

- An independent input wired to a timer controlling a contact. Spring wound timers are the least expensive approach to this since they require no external power supply. However, some owners find the ticking sound associated with them to be annoying. In these instances, providing a powered timer is necessary, which requires power wiring in addition to the pair of wires that monitor the contact. These switches can be purchased with a feature called a “Hold” setting that locks the switch on. This feature is not desirable for an override application because it allows the tenants to easily defeat the scheduled fan operation by locking the switch on. Key activated switches can be provided if an owner only wants certain parties to have access to the override feature.
- Some systems provide an auxiliary switch as an option on their zone temperature sensors. One approach may include an independent contact that is simply housed inside the thermostat and requires an independent input. Another approach uses one pair of wires to monitor temperature, switch status, and drive a digital temperature display.
- Some systems, either as a standard option or via an interface with independent third party equipment, can provide tenant override capability through a phone connection. Generally, this approach provides each person authorized to initiate an override function with an access code. Some systems also allow the start time and number of hours to be entered rather than simply starting a fixed override cycle when the authorization code is entered.

Regardless of the approach used, the system can be programmed to accumulate the hours of override operation for each switch and report and archive the data. This feature allows owners with tenants who lease the space to bill for extra HVAC operation beyond the normal hours provided. Tracking override hours can be a strong energy conservation incentive because it makes the tenants accountable for their use of the system after hours. Owners with multiple departments can employ similar tracking in which the extra hours are billed to the departments.

### 3.4.3. Calibration Test Ports

Without sensor test ports, it is difficult to verify the calibration of installed sensors. While absolute calibration in the field is difficult, it is still important to have a way to cross-check the indication from an operating sensor with the system online and without removing the sensor from the system or control circuit.

To facilitate installation of calibration test ports, all piping penetrations should be put in place in the construction phase. Putting a weldolet into an empty piping system during initial pipe fitting work takes one pipe fitter about 20-30 minutes or less. Installing the same weldolet after the system is online can take a crew of two or three people a day or more if a welding machine must be set up and a portion of the system must be drained and refilled. This process could require an outage if the sensor is in the main piping. Designers and commissioning providers should review all sensor and test port locations with the contractor early in construction by marking the pipe or duct together and then verifying the locations before filling the system. The test port should be a self-sealing plug rated for the temperature, pressure, and fluid associated with the application. The following bullets set forth guidelines for different types of calibration test ports.

- **Temperature** For every temperature sensor well, there should be a second well for a calibration thermometer immediately adjacent to the sensor well. Pete's plugs should be used when both temperature and pressure measurements are needed. Thermometer wells are more desirable for temperature-only measurement sites because they will never have seal failure.
- **Pressure** Every gauge cock should have a second valved connection to allow a calibration gauge to be connected to the system. Pete's plugs are good for locations where only occasional measurements are required. Differential pressure transmitters should have 3 or 5 valve manifolds to prevent them from being decalibrated or damaged when placed online. Install isolation valves and test ports at each pressure sensor location.
- **Flow** Field calibration of a flow meter is very difficult, and providing test ports for calibration is generally not practical. If field calibration is attempted, a calibration device that is as accurate as the flow meter must be installed in series with the flow meter, or the flow meter can be removed and replaced with the calibration instrument.

### 3.4.4. Calibrating Analog Inputs

This section discusses calibration methods for analog and binary inputs or outputs. In general, all hardware and software calibration information should be documented in a log. The rigor of calibration for any sensor depends on the sensor application. Calibration should be performed using a standard that is as accurate or more accurate than the sensor being calibrated. It is also important to understand exactly what is being calibrated with different procedures.

For instance, unless the current is measured at the 4-20 mA level, the 4-20 mA input is a function of some other parameter. So, if calibration is performed using a 4-20 mA generator, you have verified that the control system will interpret the 4-20mA correctly, but you are relying on the 4-20 mA transmitter to interpret the sensor output correctly. A better calibration approach might be to hook a decade resistance box up in place of the RTD and calibrate to that. Of course, then you are assuming that the RTD is correct. So, the best approach is to put the RTD in a fluid or dry bath and subject it to temperature extremes and reference it against this known standard. The sensor should be subjected to a temperature near the low end of its span to set the zero adjustment on the transmitter. Then the sensor

should be subjected to the high end of its span to set the span adjustment on the transmitter. Since some transmitters have interactive span and zero adjustments, (changing one affects the other slightly) repeat the calibration process several times. Higher end transmitters may have non-interacting zero and span, but it is wise to verify the calibration at least once. Calibrating with a reference fluid temperature the most accurate method, but is a very difficult and expensive process to accomplish in the field. A factory-calibrated sensor can solve the problem of field calibration.

#### **3.4.4.1. Factory calibrated sensors**

High precision calibration in the field can be time-consuming and costly. Purchasing factory-calibrated sensors with calibration certificates adds some cost to the sensor prices, but typically this cost is much less than calibrating in the field. A factory calibrated sensor and transmitter are assumed to be accurate unless proven otherwise, so the installing contractor should not make adjustments to the zero and span of the transmitter. Factory-calibrated sensors should be checked in the field, but not calibrated. If a calibration problem is identified during the check, the factory must correct the problem since they did the traceable calibration.

#### **3.4.4.2. Calibration at the transmitter or the BAS**

Most transmitters have zero and span adjustments for field calibration. Control systems also have zero and span adjustments for each I/O point using slope and intercept values or other database parameters. So where should you make the adjustment of zero and span - in the control system or at the transmitter?

If the sensor does not have a transmitter or device that allows calibration at the sensor (an RTD or a thermistor for instance), then the adjustments must be made at the control system database. If the sensor is replaced, then make sure to look at the database and make changes if necessary. If someone tweaked the slope and intercept at the control system database to field tune the previous sensor, then leaving these old parameters in the database will most likely decalibrate a newly installed sensor.

If possible, calibration should be performed at the transmitter to allow sensors to be interchangeable. Then if a sensor is replaced, it is not necessary to remember to modify the control system database calibration parameters.

#### **3.4.4.3. Single and Multi-point calibration**

Single point calibration is accurate enough for sensors that will typically only sense at one point, like space temperature. Single point calibration can also be used for a point that is controlled for a fixed value all of the time when the accuracy of the sensor is not as important as knowing a fixed setpoint. For example, a discharge temperature on a system with no reset can be calibrated at only one point. Documenting and keeping track of how the sensor was calibrated allows you to let others know so that a reading does not mislead them at a point other than the calibration point.

A typical method for single point calibration is to compare the control system display to one measurement from a calibrated instrument. The calibration should be made at a typical value for each sensor, by an instrument at least as accurate as the sensor that is being calibrated. This method can be inaccurate if the span is not adjusted correctly or if the device is not linear.

Multi-point calibration should be done when accuracy over a range of values is important. A typical method for multi-point calibration is to compare the control system

display to two or more values measured by a calibrated instrument. For linear devices, calibration points should occur at the high and low limits of typical operating conditions. For non-linear devices, three or more points should be compared to the sensor look up table or curve fit with both rising and falling signals. In HVAC, calibrating non-linear inputs typically only applies to thermistors. When replacing thermistors, the new thermistor must be calibrated because the sensors are not necessarily interchangeable.

#### **3.4.4.4. Calibration verification through energy and mass balance**

Calculating energy and mass balances is one way to verify that sensors agree. Verification of calibration is especially important for systems where temperature differences are used for control decisions (i.e., airside economizers, hydronic systems). However, an absolute energy or mass balance may not be achievable due to sensor accuracy issues. Instead of taking data off the control system for the energy or mass balance, take differential readings with the same sensor to cancel out the sensor error. A thermal or mass balance indicates a problem worth investigating if the balance is outside of the worst-case window based on the sensor accuracy rating.

Examples of these checks are listed below:

- When the outdoor air dampers are fully open, the outdoor air temperature and the mixed air temperature should be equal.
- When the cooling and heating coils are closed, verify that the mixed air temperature equals the supply air temperature.
- Compare the supply air flow (outdoor air + return air) to the sum of the VAV box flows.
- The air side and water side numbers for a coil should create a thermal/mass balance.

#### **3.4.4.5. Matched sensors**

The manufacturer can select two sensors with nearly identical output characteristics so that the differential they measure is accurate. Without matched sensors, one sensor could read on the high side of the tolerance (+0.5°F) and the other on the low side of the tolerance (-0.5°F), resulting in a differential accuracy of  $\pm 1^\circ\text{F}$ . Having matched sensors can make energy and mass balances a more reliable means of calibration verification. As an alternative, two sensors can be matched through field calibration only if calibration instruments are more accurate than the sensors. Otherwise, you may be decalibrating the accurate sensor to match the inaccurate sensor.

#### **3.4.4.6. Relative Calibration**

In many instances the relative calibration of sensors in a system is more critical than their absolute calibration within the constraints of their specified accuracy. For the purposes of our discussion, relative accuracy is defined as the accuracy of the sensors relative to each other and perhaps some field reference standard. Absolute accuracy is the accuracy of the sensor relative to a NBS traceable standard. Two sensors that have been calibrated to the same standard with the same accuracy specification will have the same absolute accuracy.

More detailed information about relative calibration can be accessed in the Functional Testing Guide, *Section 18.3.2: Relative Calibration Test*. From there, a link to a relative calibration test procedure template is provided.

### 3.4.5. Calibrating Analog Outputs

Calibrating analog outputs essentially consists of calibrating the analog inputs in reverse. Calibration should verify that the valves and dampers have correctly stroked through their full range. Additionally, the position indicators on the actuators should be verified, and the start and span setting of any positive positioners should be inspected.

One signal may be used to sequence a number of actuators by taking advantage of different spring ranges. This type of sequencing deserves careful calibration to make sure each valve fully strokes at the appropriate time.

For valve and damper actuator design and testing information, see the Functional Testing Guide, Chapter 11: Preheat.

### 3.4.6. Calibrating Binary Inputs and Outputs

Binary inputs show status, or proof of operation, of equipment. Calibration of binary inputs should be done in conjunction with the binary outputs. This task verifies that the proof of operation point reports the correct status.

For binary outputs, calibration involves verifying that the command from the controller results in the correct action. During calibration, the actuation point (the value at which the sensor switches from ‘off’ to ‘on’) is checked to verify that it is within tolerance. The switching differential, or deadband, may be too small or too large. If the differential is too small, then the output may switch from ‘off’ to ‘on’ so rapidly that the point “flutters”, which can reduce component life. If the differential is too large, then once the switch turns on, it may never switch back.

## 3.5. Sensor Selection and Installation Guidelines

Correctly specifying and installing a sensor is based upon the importance of each point to system control and efficiency. The accuracy of each sensor should be tailored to the purpose and requirements of the function it serves. To be valuable, some monitoring functions will require better accuracy than some control functions. The reverse case can also be true. The absolute accuracy recommendation presented in this section is not as important as understanding what you are trying to measure and then matching the specification to the measurement requirement.

The following sensor selection guidelines, organized by sensing application, help designers specify sensor accuracy and installation procedures. Accuracy guidelines refer to combined effect numbers that take into account errors from the sensor to the terminals of the controller, including sensor errors, lead wiring effects, and scaling resistor errors.

### 3.5.1. Temperature

In this section, accuracy, installation, and calibration recommendations are presented for the following HVAC temperature sensor applications:

- [Space temperature](#)
- [Duct temperature](#)
- [Averaging sensor applications](#)
- [Outdoor air temperature](#)
- [High temperature applications](#)
- [Critical control, monitoring, and billing applications](#)
- [Water temperature differentials 20°F or less](#)

Depending on the function, temperature sensors can have a range of required accuracies in HVAC applications. Inaccurate sensors can lead to energy waste and uncomfortable space conditions. Critical temperature sensors and sensors where errors may cause significant energy waste, loss of performance, or problems with process or production may warrant more accurate standards and more frequent calibration verification. In some processes, relative calibration may be more important than absolute accuracy.

Consider a discharge air temperature sensor that reads two degrees high. The controller achieves a 55°F discharge temperature, but is actually cooling the air to 53°F. For a fairly efficient chiller plant (0.8 system kW/ton) and a 40,000 cfm constant volume reheat air handler, this two degrees of extra cooling translates to 5.8 kW of demand. Based on a typical 2,600 hour office building operating schedule, this will save 15,000 kWh per year which equates to about \$1200/yr<sup>7</sup> (for a 24 hour operation, over \$4000/yr). To maintain comfortable conditions, the overcooled discharge air is reheated at the zones using hot water coils. For a hot water plant efficiency of 80%, the reheat energy for a 2,600-hour operating year is about 2800 therms, or \$1400/yr<sup>8</sup> (for 24 hour operation, over \$4700/yr). The moral of this story is clear - selecting temperature sensors with the appropriate accuracy for the application and making sure they are calibrated is essential for energy efficiency.

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<sup>7</sup> Assume \$0.08/kWh. This value includes both electricity consumption and demand charges.

<sup>8</sup> Assume \$0.50/therm of natural gas.

**Table 3.1 Temperature Measurement Technologies**

Technology	Function	Advantages	Disadvantages
<b>Thermocouple</b>  <i>Example application: Boiler flue gas</i>	Applying heat to the junction point of two wires made of dissimilar metals generates a voltage that is temperature-proportionate.	Inexpensive, rugged, good for high temperature applications, no external power supply required	Nonlinear, the lowest accuracy, cold junction reference required, potential calibration errors can be introduced if not properly wired using the correct type of wire that is matched to the thermocouple metals. The highest precision wire accuracy is the larger of $\pm 4\%$ of reading or $2^\circ\text{F}$ .
<b>Resistance Temperature Detector (RTD)</b>  <i>general purpose</i>	The resistance of a metal (wound wire or thin film) is temperature-sensitive.	Nearly linear over a wide range of temperature ( $-260$ to $650^\circ\text{C}$ ). Good long-term stability. Very accurate over a wide range of operating temperatures. Can be utilized as averaging sensor. Little need for recalibration of the sensing element itself, although transmitters associated with them typically require some calibration to correct for thermal drift and other effects.	More expensive than a thermocouple or thermistor. Though often applied in HVAC applications without it, they require lead wire resistance compensation or a transmitter at the RTD to allow the full benefit of the accuracy and stability of the technology to be realized. A transmitter also can add inaccuracy into the signal. Subject to moderate self-heating.
<b>Thermistor</b>  <i>narrow span application like space temp</i>	The resistance of a semiconductor is temperature-sensitive. Typically the relationship is inverse; i.e. the resistance decreases as the temperature increases. Most of the other temperature elements have a direct relationship between their output and temperature.	High sensitivity ( $-80$ to $150^\circ\text{C}$ ). Large resistance compared to a RTD, so lead wire resistance errors are negligible. Low cost. Good for point sensing applications requiring high precision over a limited range.	Non-linear beyond small range. Self-heating due to high resistances can decrease accuracy, not as interchangeable as other technologies. Higher tendency to drift over time than some other technologies.
<b>Integrated circuit</b>  <i>Tend to be OEM applications since not as many systems set up to take it as input</i>	The voltage-current relationship of solid-state devices (diodes, transistors) is temperature-sensitive.	Linear high level output at a low cost. Can be easy to interface with other electronics.	Temperature measurement range is smaller than thermocouples or RTDs, but adequate for most HVAC applications. Subject to self-heating.

### 3.5.1.1. Space temperature

<b>Accuracy</b>	$\pm 1^{\circ}\text{F}$ to $\pm 1.5^{\circ}\text{F}$
<b>Installation</b>	Locate the sensor away from electronics and other heat sources. Avoid locations where air diffusion may be stagnant. Also avoid exterior walls and stud cavities that connect to plenum floors since infiltration and surface wall surface temperatures can affect what the sensor is reading. It may be necessary to completely insulate the mounting box or mount the thermostat on an insulating pad. It is also important to make sure that small jets of air created by infiltration or pressurized air from a plenum exiting through the stud cavity and hitting the sensor are eliminated.
<b>Calibration</b>	Calibrate sensor if complaint or troubleshooting calls warrant and/or based on sensor drift specifications from the manufacturer. For instance a lower quality thermistor may show a drift of $0.1^{\circ}\text{F}$ per year, which could add up over 5-10 years. If a space never seems to come under control, it's probably worth going and taking a look. You may discover that the sensor is accurately reporting what it is seeing, but its being influenced by a draft, infiltration or cold surface.

There may be some spaces that require a closer specification, like an operating room or a clean room. In general, use thermistors or RTDs, with or without transmitters. The lowest cost approach is typically a thermistor without a transmitter, but the long-term stability of an RTD may make it a better choice.

### 3.5.1.2. Duct temperature

<b>Accuracy</b>	$\pm 0.5^{\circ}\text{F}$ to $\pm 1.5^{\circ}\text{F}$
<b>Installation</b>	Higher velocities will improve response time due to improved convective heat transfer characteristics. Averaging sensors need to see uniform mass flow rates to reflect a true average temperature.
<b>Calibration</b>	Sensor error leads to energy waste (see sidebar above – <a href="#">Implications of Inaccurate Temperature Sensors</a> ). Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

If it is an averaging sensor, the practical tolerance is  $1.5^{\circ}\text{F}$ . See the averaging sensors discussion below. On large systems, tighter tolerances are desirable because the energy waste from small errors can be considerable over time.

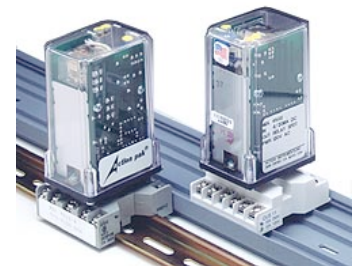
### 3.5.1.3. Averaging sensor applications

<b>Accuracy</b>	$\pm 1.5^{\circ}\text{F}$
<b>Installation</b>	For large duct cross sections with the potential for stratification, it is important to use an averaging sensor that fully traverses the duct. Mixed air plenum temperatures can vary by 5-10°F in well designed, well commissioned plenums and up to 60 °F in a poorly designed and commissioned system.
<b>Calibration</b>	See calibration discussion on multiple averaging elements below.

Averaging sensors are necessary when air is not adequately mixed and stratification occurs. There can be temperature gradients in both directions, although for most systems, one will predominate due to geometry issues. Averaging sensors can consist of a string of thermistors or RTDs wired in series. Averaging RTDs can also be constructed by stringing the resistance wires back and forth inside the wire casing to form a length of resistance. Even when using the longest versions of the averaging sensors (about 25 feet), large ducts may not be adequately traversed, especially if temperature gradients exist in multiple directions. Therefore, it is desirable to average a number of the averaging temperature sensors to increase the accuracy of the reading. As a rule of thumb, 1 foot of averaging sensor should be used per four square feet of duct cross sectional area.

There are three main ways to generate an average signal from multiple temperature sensors:

- **Software averaging** A number of RTD or thermistor averaging sensors can be hardwired or transmitted using current loops to a controller and the inputs can be averaged in the controller software. An advantage to this method is that all the input temperatures are displayed separately and shown as an average. Disadvantages include the added cost of transmitters for each averaging sensor and the additional I/O points used on the controller.
- **Independent signal conditioner** Function modules exist that allow customized process controls to be built. An averaging function module takes multiple temperature input resistances and outputs one current signal. This strategy can cost less than adding a transmitter for each input.
- **Series/parallel resistance network** Averaging can be accomplished by the sensor connection configuration, taking advantage of the way parallel and series resistances add. If four resistance temperature sensors are used, two pairs should be connected in series, then the pairs connected in parallel. The same principle applies to resistor networks of nine (or sixteen) resistors, with either three (four) sets of three (four) resistors in series wired in parallel. This method should only be used for applications where the temperature each resistor measures varies over approximately the same range. The series/parallel resistance network is a low-cost way to average sensors,



**Figure 3.5 Typical Function Module**

(Image courtesy of Eurotherm Controls)

with only one input to controller. One drawback to this method is that it is not widely used and therefore it may not be straightforward.

#### Field calibration of averaging sensors:

- 1** Use a data logger with 4-8 matched sensors for calibration. The sensors can be matched from the factory or matched to a common reference point. If they are not matched, then the offsets should be documented and applied to the readings.
- 2** Place the sensors to represent the entire averaging element location.
- 3** Create a uniform, non-stratified temperature profile by using 100% return air or a fixed setting on the preheat coil with non-varying load.
- 4** Let the temperature stabilize and mathematically average the data logger measurements. Compare the data logger and averaging element values.
- 5** Perform a two-point calibration, or a single point calibration to a temperature near the operating temperature. If the averaging sensors have a calibration problem, the element can be replaced if it is excessively inaccurate or the slope and intercept at the transmitter can be tweaked.

### 3.5.1.4. Outdoor air temperature

<b>Accuracy</b>	$\pm 0.5^{\circ}\text{F}$ or better for temperature
<b>Installation</b>	For an accurate reading, the outside air sensor should be installed on the north side of the building, shielded from the sun. The sensor should be located in free air that is not heated by exhaust air or heat from the building or roof. Radiant effects can be significant and should be guarded against. On some sites, it may be desirable to experiment with data loggers placed at various locations to select the best location for this sensor.
<b>Calibration</b>	Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

Outdoor air temperature measurement can significantly impact building energy consumption since many operational decisions are based on this temperature. Sensor error can affect the economizer cycle and reset schedules. The outdoor air conditions can also be used in degree-day and enthalpy calculations.

### 3.5.1.5. High temperature applications

<b>Accuracy</b>	$\pm 2^{\circ}\text{F}$
<b>Installation</b>	Use the thermocouple wire well within its temperature rating.
<b>Calibration</b>	Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

For many high temperature measurements, such as boiler flue temperature, accuracies in terms of plus or minus several degrees are adequate. There are instances however where tight accuracy is important for reasons of product quality control or other factors, and

accuracy specifications of a degree or less are required. In these cases, RTDs and RTDs coupled with transmitters generally offer the best solution. Thermocouples are economical and adequate when accuracy is not as important.

### 3.5.1.6. Critical control, monitoring, and billing applications

<b>Accuracy</b>	$\pm 0.1^{\circ}\text{F}$ to $\pm 1^{\circ}\text{F}$ depending on the application and how the measurement is taken and used. Relative calibration may be more important than absolute accuracy, so matched sensors are effective. A sensor that can measure accurately to one-tenth of a degree needs to be coupled with a system capable of being controlled to that level.
<b>Installation</b>	Need to minimize other sources of error like installation errors, transmission errors, etc. An RTD that looks really good can be made less accurate by hooking it up to a transmitter. Using it directly with lead length compensation may be a better option and may drive the decision about what controller or control system you are going to use.
<b>Calibration</b>	Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

Many consumption calculations rely on differential temperature measurement as a part of the energy consumption formula. In these instances, the accuracy of the sensor can have a significant impact on the calculated result. There is little tolerance for error if the data will be used for performance verification and diagnostics, or if billing is based on these measurements.

For instance, consider two sensors that have  $\pm 1^{\circ}\text{F}$  degree accuracy and are to be used in a tons calculation. Assume that there is a known constant flow of through the chillers and one sensor reads one degree high and the other reads one degree low. For an actual chilled water temperature differential across the chillers of  $12^{\circ}\text{F}$ , the inaccuracy of the temperature sensors represents 17% of total system capacity.

### 3.5.1.7. Water temperature differentials $20^{\circ}\text{F}$ or less

<b>Accuracy</b>	$\pm 0.5^{\circ}\text{F}$ or better, or as driven by the needs of the application. This is another area where relative calibration may be more important than absolute calibration.
<b>Installation</b>	For any temperature differential, a matched pair of sensors will eliminate error based on the calibration of one sensor relative to the other.
<b>Calibration</b>	Install calibration wells. Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

A  $1^{\circ}\text{F}$  error on a chilled water system with a  $10^{\circ}\text{F}$  differential represents 10% of system capacity. Less accuracy than this can make the measurement useless.

### 3.5.1.8. Water temperature differentials of over 20°F

<b>Accuracy</b>	± 1°F or better
<b>Installation</b>	For any temperature differential, a matched pair of sensors will eliminate error based on the calibration of one sensor relative to the other. As the temperature differential increases, the effect of unmatched sensors decreases.
<b>Calibration</b>	Install calibration wells. Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

## 3.5.2. Humidity

The two most common humidity sensing technologies are bulk polymer resistive and thin film capacitance. Lithium chloride salts are an older technology, and chilled mirror hygrometers are often used for precise humidity control for labs and clean rooms.

**Table 3.2 Humidity Measurement Technologies**

Technology	Function	Advantages	Disadvantages
<b>Bulk Polymer Resistive</b>	Measures change in resistance as the polymer absorbs or emits molecules of water.	Surface contamination will not affect accuracy. Some sensors are interchangeable without calibration.	Variable accuracy with changes in temperature.
<b>Thin Film Capacitance</b>	Measures change in capacitance between a thin film polymer and electrode due to change in relative humidity.	High linearity, low hysteresis, long-term stability, wide temperature range. Some sensors are interchangeable without calibration.	Variable accuracy with changes in temperature
<b>Lithium Chloride Salts</b>	Saturated salt solutions produce a known RH. Often used for calibration of sensors.	One of the older technologies; was available before capacitance and thin film technologies were developed and was actually one of the more cost effective approaches	Sensitive to dirt and moisture contamination, expensive, requires frequent calibration.
<b>Chilled Mirror Hygrometer</b>	Mirror chilled through thermoelectric cooling until dew/frost forms. The dew point temperature is measured by an RTD.	Inherent accuracy since measure dew or frost point temperature directly. Long-term stability.	Expensive relative to some of the new technologies. Contaminants on mirror reduce accuracy, so cleaning is required. Some of these sensors have a self-cleaning cycle.

#### Accuracy

± 5% of reading represents a compromise between accuracy and first cost. For critical applications (clean rooms and operating rooms), ± 3% or better can be achieved. Obtaining a higher level of accuracy can increase the sensor cost from hundreds to thousands of dollars.

#### Installation

Outdoor air humidity should be picked up at the same location as the outdoor air temperature.

#### Calibration

The humidity sensor needs to be immersed in salts or a humidity reading must be taken using a sling psychrometer in the duct location. This is usually easiest with a sling

psychrometer that has a built in fan so you can set it in the duct and let it run. Swinging a sling in a small duct can be tricky, and an access panel is necessary. Salts can be used for calibration by pulling the transmitter out of the duct, but it needs to be mounted so this is possible (flex connection, big enough probe opening to retract probe and turn it with the flex attached, etc.). Otherwise you need an access panel.

### 3.5.3. Pressure and Flow

Table 3.3 presents a variety of pressure measurement technologies for air and water. The capacitance, strain gauge, and piezoresistive technologies compete with each other since they offer accuracy at a reasonable cost in a variety of levels of quality. LVTDs compete with the lower end versions of these technologies. For all of these devices, pressure transients in the air or water may cause erroneous readings. For example, pressure pulses from the pumps can create noise in the pressure measurement. A pressure pulse can also be created from a door opening that is near a diffuser location and near the duct static pressure measurement point. In this case, the pressure pulse can cause the control loop to hunt.

**Table 3.3 Pressure Measurement Technologies**

Technology	Function	Advantages	Disadvantages
<b>Velocity Probes</b>  <i>Example application:</i> <i>isolation rooms</i>	Measure pressure differential based on velocity through a tube across the pressure difference.	Can accurately and repeatably measure to thousandths and ten thousandths of an inch water column; good for low pressure applications like clean rooms, building pressure control and isolation room monitoring or control where pressure differentials in the range of 0.05 in.w.c. or less must be accurately measured and maintained.	More expensive than other technologies, sensing line length critical since there is active flow through the lines - long lines could impact the accuracy of the input because the pressure drop through them would affect the flow and flow is the indicator used to measure pressure differential.
<b>Manometer</b>  <i>Example application:</i> <i>filter pressure drop</i>	Measure the change in height of a column of liquid between a reference pressure and the pressure being measured. Typically a manual instrument used to calibrate and verify other instruments.		
<b>Capacitance</b>	Pressure changes cause a change in capacitance between a metal diaphragm and an electrode. The capacitance is measured and used to generate an output signal.	Low hysteresis, high repeatability, high resolution, fast response, and the ability to measure low pressures.	Must be zeroed routinely since temperature or change in physical position can affect performance. May not be as rugged as some other technologies.
<b>Strain Gauge</b>	The deflection of a diaphragm due to pressure change is measured by strain gauges.	High accuracy, long-term stability; very tolerant of extreme over-pressurization in some packages.	Strain gauge bond with diaphragm may degrade
<b>Piezoresistive</b>	A pressure change causes the resistance of a semiconductor (solid-state chip) to vary.	Detects larger pressure differences than capacitive transmitters (greater than 5"). Withstands vibrations.	
<b>Linear Variable Differential Transformer (LVDT)</b>	An electric output is produced in proportion to the displacement of a movable transformer core. Usually coupled to a bourdon tube to measure pressure.	High reliability since no mechanical wear/friction between the transformer core and coil. High resolution. Lower cost for a given accuracy spec as compared to some other technologies.	Inherent nonlinearity of standard LVTDs is about 0.5% of full scale. Not as rugged or accurate as some other technologies.

Differential pressure-based flow readings are a function of the square of the flow (at 50% of full flow, the signal is 25% of full flow), so the signal becomes less accurate at low flows (high turndown). If differential pressure based measurements are being employed to measure flow, it is important to consider the magnitude of the available output signal that will be generated at the lowest flow point that the system can be expected see.

Smart differential pressure transmitters can get up to a 10:1 turndown, but another way to get better turndown is to hook up multiple transmitters to a flow sensor and then have the software pick the one that is best for the current flow range. For example, one transmitter is full scale at 25% of design flow, one is full scale at 50% of design flow, and one is full scale at 110% of design flow. The lower range transmitters must be rated to withstand the higher differential pressures (beyond their range) without failure.

The maximum output of the flow meter should be chosen at 5-10% above design conditions to guard against over-range errors at start-up and overload conditions. This sizing is important in flow measurement applications because the sensor ranges tend to be customized to the application rather than being defined by physics (like 0-100% RH) or being defined by standard ranges based on the HVAC process.

**Table 3.4 Differential Pressure-based Flow Measurement Technologies**

Technology	Function	Advantages	Disadvantages
<b>Pitot Tube</b>	Measures velocity pressure at a point. Flow is then calculated based on the velocity pressure. Typically used for manual measurements with an inclined or electric manometer or as a sensing probe for one of the pressure transmitter technologies listed in the Pressure Measurement section.	Fairly inexpensive but must be combined with some sort of indicator or transmitter to provide useful data and/or interface with a control system. Little need for calibration. Low pressure drop. Small access holes.	Small tube misalignment results in poor accuracy. Reliable measurement requires multiple pitot tubes. Flow output is a function of the square of the velocity pressure, so Turn down capabilities are not good. For example, 50% flow produces only a 25% signal.
<b>Orifice</b>	Pressure is measured before and at restriction in liquid flow (orifice plate). Velocity is calculated from the pressure drop using conservation of energy and mass equations. Combine with an indicator or transmitter to provide useful data and/or interface with a control system.	Lower first cost relative to the more exotic technologies.	Energy penalty from high pressure drop. Flow output is a function of the square of the velocity pressure. 50% flow produces only a 25% signal, so turn down capabilities are not good.
<b>Nozzle</b>	As above, but restriction is a nozzle internal to the pipe, with no expanding outlet area for pressure recovery. Combine with an indicator or transmitter to provide data and/or interface with a control system.	Lower first cost relative to the more exotic technologies. Used for high velocity flow.	Pressure drop lower than an orifice plate, but higher than a venturi. (and same problems as far as turn down and signal go)
<b>Venturi</b>	As above, but restriction is a gradually narrowing diameter of pipe, followed by an expanding section. Combine with an indicator or transmitter to provide data and/or interface with a control system.	Lower first cost relative to the more exotic technologies. Nearly returns the flow to its original pressure. High accuracy, used for larger pipes.	(and same problems as far as turn down and signal go)
<b>Insertion Tube</b>	Measures velocity pressure. Combine with an indicator or transmitter to provide useful data and/or interface with a control system.	Low pressure loss. Often, this probe can be installed in an operating system via a hot tap, thereby eliminating a shut down.	Flow output is a function of the square of the velocity pressure. 50% flow produces only a 25% signal, so turn down capabilities are not good.

**Table 3.5 Non DP-based Flow Measurement Technologies**

Technology	Function	Advantages	Disadvantages
<b>Hot Wire Anemometer (Airflow)</b>	The heat lost due to airflow across a heated sensor is correlated to air velocity. Some technologies measure the heat transferred from one sensor relative to another to detect flow rate and direction	High frequency response. Good for low flow measurements. Good for high turn-down applications.	Fragile, only used in clean air flows. Calibration is required frequently. High cost.
<b>Rotating Anemometer</b>	Vanes spin and velocity is measured. Typically used for manual measurements.	Portable, low cost, can detect and measure low flow rates.	Small tube misalignment results in poor accuracy. Reliable measurement requires multiple readings
<b>Vortex Shedding Sensor</b>  <i>Example application: Steam flow</i>	Measures the frequency of pressure spikes due to vortices made by inserting the vortex probe in the air or liquid stream. The frequency of the pressure spikes is translated into fluid velocity.	Highly accurate. High turn down ratio.	For steam, mass flow varies with line pressure. High first cost relative to some of the other lower accuracy, lower turn down technologies. difficult to field calibrate. Needs to be sized and may be smaller than line size to provide the necessary turn down capability.
<b>Critical Flow Nozzle</b>	The gas (air, steam, oxygen, etc.) reaches the velocity of sound through the nozzle, which cannot be exceeded. The mass flow rate is proportional to the pressure upstream of the nozzle since the velocity through the nozzle is fixed. Must be combined with an indicator or transmitter to provide useful data and/or interface with a control system.	Requires only two measurements (inlet static pressure and temperature).	Nozzle and diffuser result in 10% reduction in upstream pressure, so used in steam transitions to lower pressure applications.
<b>Positive Displacement</b>	Applications include water metering such as for potable water service, cooling tower and boiler make-up, and hydronic system make-up. Positive displacement meters are also used for fuel metering for both liquid and gaseous fuels. Common types of positive displacement flow meters include lobed and gear type meters, rotating disk meters, and oscillating piston type meters.	high accuracy at high turndown	high permanent pressure loss close tolerance required between moving parts of positive displacement flow meters, they are sometimes subject to mechanical problems resulting from debris or suspended solids in the measured flow stream High cost. Loss of flow if the meter fails or seizes up.
<b>Turbine</b>	Flowing water rotates a turbine in the pipe, speed of rotation is detected and related to the velocity of the fluid.	Full bore turbine for critical flow measurements. Good turndown. Often, this probe can be installed in an operating system via a hot tap, thereby eliminating a shut down.	Pressure loss, but less with insertion type. Reduced accuracy and susceptible to damage with debris in water. Bearing life problems.
<b>Transient Time Ultrasonic Flow Meter</b>	Ultrasonic waves are sent with and against the direction of fluid flow, measuring the time difference for the wave to travel.	Non-invasive (strap-on or weld on) or in-line meter. Very good turn-down capability. Often, this probe can be installed in an operating system via a hot tap, thereby eliminating a shut down.	High first cost relative to some of the other lower accuracy, lower turn down technologies. Used to measure clean water flow. Errors in readings when air trapped in pipes or with dirty water. Difficult to field calibrate.

<b>Doppler Ultrasonic Flow meter</b>	Sound waves are reflected back to the sensor from solids or bubbles in the fluid. The echoes return at an altered frequency proportionate to flow velocity, which is measured to calculate flow.	Non-invasive (strap-on) or in-line meter. Liquids measured must contain solids. Often, this probe can be installed in an operating system via a hot tap, thereby eliminating a shut down.	High first cost relative to some of the other lower accuracy, lower turn down technologies. Difficult to field calibrate.
<b>Magnetic Flow Meter</b>	Magnetic induction: water (a conductor) moves through a constantly applied magnetic field and a voltage is induced proportional to the speed of the water.	In-line meter has high accuracy. High turndown ratio (30:1). Low maintenance.	High first cost relative to some of the other lower accuracy, lower turn down technologies. Difficult to field calibrate.
<b>Target Flow Sensor</b>	An arm with a disc at right angle to flow measures the force of fluid flow.	Can be used with dirty fluids. 20:1 turndown	

### 3.5.3.1. High Pressure Applications

#### Accuracy

For flow metering applications, the sensor should be selected for  $\pm 2\%$  of full scale with full scale selected to match the meter output at 110% of the maximum flow.

Pressure transmitters for piping:  $\pm 1\%$  of full scale or better. The standard gauge ranges for pressure transmitters for water and steam systems and other relatively high pressure fluids are typically 30, 50, 100, 150 psi, so 1% of full scale as a rule implies accuracies of 3-15 psi depending on the range. Ultrasonic, magnetic flow, and vortex shedding meters can achieve  $\pm 5\%$  of the flow reading or better with turndown ratios of at least 15:1 to 30:1. Vortex meters can also be used on steam and compressed air systems for superior turn-down capabilities.

#### Installation

The upstream and downstream lengths of straight piping are important to consider for accurate flow measurement. During design, the piping layout should incorporate the manufacturer requirements for straight run in and out of the flow sensor. Installing the sensor just after and just before tees or elbows will result in an inaccurate reading.

For field-welded meters with precise sensor alignment requirements (ex., ultrasonic flow meters), adjustment jigs that are specific to the meter should be used for installation. These jigs usually need to be provided by the supplier. If the ultrasonic meter alignment is correct, then any sensor error should be related to the electronics and transmitters, which can be removed and returned to the factory for re-certification. A venturi meter or orifice meter usually does not have a special jig.

#### Calibration

Calibrating water flow meters is very difficult, since it is not always practical to install the flow meter in a location that provides enough room to add an additional calibration flow meter at the location. Using a calibration technology more accurate than the installed flow meter can also be difficult. In many cases, factory calibration is the only practical option. Differential pressure measurement across a chiller, pump curves, or calibrated balancing valves can be used as a cross-check, rather than actually calibrating to the device. For a precise flow meter, like some of the electronic technologies, using differential pressure for a calibration reference would probably decalibrate the flow meter.

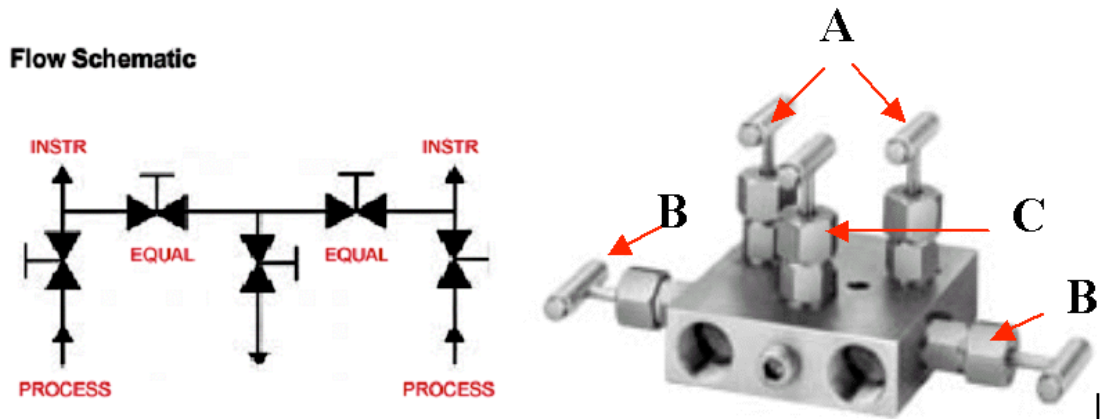
One possibility is to make provisions for the installation of a portable, strap-on ultrasonic meter in series with the permanent meter. A section of pipe must be provided with insulation that can be removed and replaced easily. There are vapor sealing issues that need to be addressed with lines that condense the insulation is removed.

A strap-on flow meter is also a viable option for a system where good readings are necessary for troubleshooting or set-up, but the facility cannot justify or afford the cost of a permanent meter. Design place places for a strap-on meter, then furnish one portable meter for the owner after the initial balancing.

## **Five-Valve Manifold**

Most differential pressure sensor locations serving high-pressure fluids require a field-fabricated or factory-built five-valve manifold. Differential pressure sensors and transmitters can be damaged, decalibrated, or destroyed by imposing the static pressure of the measured medium upon the differential pressure sensor and transmitter. There are many styles of five valve manifolds, so it is important to understand the function of each valve and install one that performs the exact function you need.

The equalizing valves, opened before the process flow valves, serve to bring the process pressure onto both the high and low sides of the differential pressure sensor at the same time. The equalizing valves are then closed and the vent between them is opened to verify that there is no cross flow bypassing the transmitter. Figure 3.6 illustrates a typical manifold and how it is used.



**Figure 3.6 Typical 5 Valve Manifold and Schematic**

Opening the equalizing valves (A) prior to opening the service valves (B) guarantees that the sensing element of the transmitter will see little if any differential pressure even if one service valve is opened before the other. Closing the equalizing valve after opening the service valves subjects the sensing element to only the differential pressure signal. Opening the vent valve (C) proves that there is no cross-flow in the equalizing line, which could throw off the measurement. Some manifolds include another pair of valves in tees next to the transmitter connection to allow air to be cleared from the lines and allow a calibration meter to be connected in parallel with the process sensor. *(Images courtesy of the Hex Valve web site)*

## Snubbers

Snubbers should be installed at all pressure sensor and pressure transmitter locations to dampen pressure pulsations in order to provide stable readings and extend the life of the pressure-sensing element. Snubbers should be installed after the isolation valve and ahead of the calibration and sensing connections. Several different styles are available, as shown in Figure A. The style selected depends on the application.



**Figure 3.7 Pressure Gauge Snubber Styles**

Some styles dampen pulses via a fine meshed porous filter (left). Others use interchangeable pistons that can be selected to tune the snubber to the process (center). Others have a field adjustable screw that allows the dampening effect to be adjusted (right). *(Images courtesy of the Ashcroft and Weiss Instruments web sites)*

## Indicating transmitters

Indicating transmitters eliminate the need for an independent indicator, saving first costs and ensuring that the reading the operators get at the equipment is the same as the control system is getting. You still need to install second well or gauge for calibration purposes.

### 3.5.3.2. Low Pressure Applications

#### Accuracy

Air flow can be measured with transmitters designed for much lower ranges, like 1/10th of an inch or even better if some of the velocity-based flow measurements are used. The accuracy necessary for airflow measurement is dependent on the need for turndown and/or absolute accuracy, specific to each application. For example, supply and return fan tracking in a VAV system with high turndown requires sensors that can measure a wide range of flow rates. To determine the absolute accuracy required, consider what would happen to system control if the flow was measured 10% low on the return and 10% high on the supply. This could be unacceptable for an operating room or laboratory with strict pressurization requirements, but satisfactory for office space.

VAV box flow is another common application for flow measurement. Most controllers use a velocity pressure signal as an indication of flow. Thus, due to the square law effect (pressure drop varies with the square of flow), the low end of the flow measurement rating (i.e., 1000 cfm for a 1000-2000 cfm VAV box) is generally set by the ability of the flow measuring element to generate a useable signal when applied at the connection size associated with the VAV unit. There are several important design and commissioning implications to this, which are discussed in Chapter 19: Terminal Equipment.

Consider the magnitude of the available output signal that will be generated at the lowest flow point that the system can be expected see. This could be equivalent of the sum of the minimum flow rates of all of the terminal units served by the system if all zones on the system operate on the same schedule. But, for a system where the schedules were applied to the zones so that an unoccupied zone was driven to 0 cfm during the unoccupied cycle while other zones remained active, it also could be the sum of the minimum flow rates of the smallest possible collection of occupied zones.

#### Installation

There are several ways to improve the signal with high turndown ratios:

- Install the flow sensors in a section of duct that is sized to provide the required velocity pressure at the minimum anticipated flow. This section could have significantly higher velocities and friction rates than the bulk of the duct system. Careful design and attention to regain considerations can minimize the impact of this approach on overall system static, but there will be some impact.
- Install flow sensors designed for the eye of the fan wheel. Velocities in this area tend to be higher than the trunk duct velocities and several manufacturers have equipment configured specifically for this type of application. Figure 3.8 is one such example.
- Use “smart” sensor technology. This approach takes advantage of digital technology to more finely resolve the velocity pressure input and provide better resolution of the signal, often in the range of 8:1 or 10:1 vs. the 4:1 or 5:1 possible with conventional differential pressure cells.

- Install multiple sensors on the flow-measuring element ranged for different percentages of the output signal and select the best sensor for the current flow condition. This allows one differential pressure sensor to be optimized for the higher flow for instance from 50% to 100% while another is optimized for the flow range from 25% to 50% and a third is optimized for 10% to 25%. (This approach can also be used for differential pressure based water or steam flow measurements.) In this application, all sensors must be capable of withstanding the differential associated with the full flow indication (which will be over-range for the sensors optimized for the lower flow rates) without damage or calibration problems. This is usually more of a problem with water and steam systems than air systems.



**Figure 3.8 Flow Sensor Designed for the Fan Wheel Inlet**

(Image courtesy of Tek-Air)

- Use an alternative technology that does not require differential pressure measurement for systems with large turn-down ratios. Hot wire anemometer based sensors are an example of this approach for air systems. Ultrasonic and vortex shedding flow meter technologies are a similar example for water and steam systems.

### Calibration

Field calibration of an air flow meter is easier than a water flow meter because you can traverse the duct at a good spot with good technique and instruments and probably get a reasonable cross-check.

### Filter Pressure Drop

Filter pressure drop can be automatically detected and compared to a set point to determine when the filter should be changed. This point is called filter status. This information can make filter maintenance easier on a constant volume system, but is not critical as long as some form of filter pressure drop indication is provided (most codes require filter pressure drop measurement either directly or by reference to ASHRAE which cites it as good practice). Installing a Photohelic™ or equivalent device that combines pressure drop indication, set point indication, and a contact closure at set point meets code requirements. Since the flow in a constant volume system is constant, the pressure drop of the filters will not vary with load on any given day, and the pressure drop observed by the operators on rounds will be a good indication of the condition of the filters.

Detection of filter status is required for VAV systems because the filter pressure drop will vary with load and flow. The peak load and flow condition, and therefore the peak pressure drop, may occur at a time when the operators are not observing the filter pressure drop indicator. Failure to realize that the filters are exceeding their rated pressure drop can lead to structural failure of the filter or blow-through of the filter media. Additionally, an unacceptable loss of system capacity can lead to performance problems, IAQ issues, and loss of efficiency due to soiling of the heat transfer surfaces downstream of the filters.

### 3.5.4. Electrical

Electrical measurements are useful to indicate proof of operation, measure efficiency, and measure power demand and energy consumption.

**Table 3.6 Electrical Measurement Technologies**

Technology	Function	Notes
<b>Current Switch</b>	Binary signal based on the current flow relative to a limit value.	Inexpensive way to measure proof of operation based on a fairly direct indicator (motor current) that can detect drive failures if properly applied and adjusted. Needs to be matched and adjusted to the system operating characteristics to reliably detect belt and drive failures on variable flow systems. Some switches will not work with VFDs due to line harmonics.
<b>Current Transformer (CT)</b>	Measures a small voltage that is proportional to the current flowing through the device. Used with current transmitter to measure current.	Some designs require a shut down to install the sensing element since it is a continuous loop that must go around conductors and bus bars. Need to be protected from an open circuit condition.
<b>Potential Transformer (PT)</b>	Steps down the voltage into a range suitable for sensing. Used with voltage transmitter to measure voltage.	
<b>kW Transmitter</b>	Used in combination with PT and a kW transmitter to measure power.	Three phase power measurements require multiple CT and PT. Can get three phase power transmitters or implement a separate transmitter for each phase and calculate the total power in the controller. Any kW reading integrated to get kWh.
<b>kW Pulse Train</b>	Pulse rate proportional to kW typically furnished by the utility	Often averaged over a 15 or 30-minute interval. Can be integrated to determine consumption (kWh).
<b>kWh Pulse Train</b>	Pulse represents the consumption of a fixed number of kWh. Keep track of kWh pulses.	

## 3.6. Point Structure and Interface at the BAS

Chapter 2, Control System Design Process, presents the components of the design of control systems. This section builds upon Chapter 2 by focusing on aspects of interfacing the control and monitoring points to the BAS that often show up as commissioning and operational issues.

The following recommendations for spending time upfront planning the point structure and user interface to the building automation system (BAS) ultimately saves time by reducing the changes that need to be made during the final phases of construction. If the control contractor needs to make changes to point names and other fundamental database parameters after the initial programming is complete, it is often necessary to modify a significant portion of the software associated with the system's operating logic because the point names show up in the software sequences as variables. In some systems, the controls contractor must literally go through all of the programming in the system and modify the name of the point at every occurrence. This can be time consuming and introduces opportunities for errors, which will require that the software be re-commissioned to verify that no new bugs were introduced by the changes and that all changes were picked up. The following BAS point structure and interface issues help make the BAS more useful in controlling and monitoring system performance:

- [Point Naming Conventions](#)
- [Virtual Points](#)
- [BAS Settings](#)
- [Programmable Alarms](#)
- [BAS Graphical User Interface](#)
- [Point Trending](#)

### 3.6.1. Point Naming Conventions

Most current technology systems have both a name and a descriptor associated with each point. Generally, the point name is short 8- to 16-character text string that is stored in the memory of the controller. In most systems, you can trace its origin to early generations of the controller architecture where the ability to store and handle text and other data strings was limited by the addressing capability of the microprocessor. The point name provides a way to link the raw data associated with a point's physical location on the input/output terminal strip with the real world data represented by the point. As a machine, the microprocessor would have no problem working with the raw numbers that represent the wire termination location on its input/output termination board. But since humans needed to work with the machine the point name provided a way to represent this data in more human terms. To be truly useful, the name had to be coded to represent both the system and information associated with the point. This representation can be somewhat cryptic since 8 or 16 characters can be used up very quickly when generating a name that is decipherable, but gives a feel for what the point represents, especially on larger systems where the name might need to reflect multiple air handling units, each with multiple points of a certain point class such as temperature.

As microprocessing technology evolved to the point where larger text and data strings could be handled, most manufacturers added point descriptors to the point's database. In most instances, the descriptor consists of a 32- to 64-character data string that enhances the point name to provide additional clarity. Since memory is still a fairly precious commodity at the

controller level, the relatively memory intensive point descriptors are often stored in memory at the host computer, operator work station, or at a supervisory controller on the network, upstream of the controller they are associated with. The descriptors are then put together with the point name by the system's operator interface software to allow them to be viewed with the points lists, graphics and other information presented at the operators terminal (host computer). If a technician is working directly with the microprocessor at the controller via a laptop computer or other programming tool connected directly to the controller's programming port, they will probably be working only with the point names unless the programming tool has the descriptors in its database and has software running that can make the association. Thus, it is advisable to code in the point names in some manner that allows them to convey the basic information associated with a point, such as the system it serves and the data it represents.

As you may surmise from the preceding discussions, point names and descriptors represent a powerful tool in making the control system useful to the operators and clarifying the information it presents. Information that is clearly presented is more likely to be responded to in a timely fashion and interpreted correctly, especially during the fast paced events associated with some sort of operating emergency. The ability to correctly interpret the data presented is also critical to the efficient operation of the facility and its equipment.

Many systems have default parameters that are used as placeholders for the memory locations associated with the point name and descriptor values. If the owner and designer do not become proactive in directing the control contractor in the point naming conventions that should be used for a project, the programming technicians may simply use these defaults since it can save them time and labor cost during system's installation and programming process. When this occurs, a great deal of the flexibility utility that can be provided creatively using these data fields will be lost, probably for the life of the system since changing this information (especially the point names) subsequent to program development can result in the need to go through all of the software in the system as mentioned previously.

Ideally designer should set the general criteria that will be used for naming points in the project's specifications. This may include a list of point naming conventions already in use on a site where the project is an expansion of an existing facility. For new projects, it might include a standard list that the designer has developed from another project and past experience. In any case, the general criteria provided in the contract documents can alert the contractor to the need to coordinate these requirements into the database and programming development cycle for the project. As a part of that process, the owner and, ideally, the future facility operators, should become involved in finalizing the naming conventions that will be used for the project. Typically, this can be accomplished as a part of the shop drawing review process. The following paragraphs describe considerations for point naming that should be addressed in the specifications and finalized prior to programming the system.

- **Label each point with a unique name** Ultimately, each point must have some unique name that distinguishes it from all other points on the system. Some systems accomplish this by arranging their database so that quite literally, each point has a unique name. However, this can become cumbersome on systems with large point counts, and many systems now organize their data in some sort of nested file structure similar to that used by with Windows operating system. Under this approach, each controller or system device has a unique name and the points residing within that device have a unique name relative to each other. But the structure of the database allows different controllers to have identical point names. For instance, controller RTU1 may have a point named RTU\_LAT with a default descriptor ANALOG INPUT and controller RTU2 may have a point with the same name and descriptor. From a programming standpoint, this approach has some significant advantages because, for projects with identical HVAC systems,

programming can be written and debugged for one controller and copied to all the others serving an identical HVAC system. The system knows the points are different because they are in controllers with different names. But, an all-points log on such a system often looks like this:

```
RTU_LAT    ANALOG INPUT    57.4
RTU_LAT    ANALOG INPUT    56.2
```

Obviously, data presented in this manner is not very useful to the operators. This can be especially frustrating when alarms come in. Having an alarm printer spit out:

```
HI ALARM    SPACETMP    ANALOG INPUT    78.0 F
```

does not give the operating staff much to go on if they are dealing with a system that has hundreds of terminal units. Contrast this with:

```
HI ALARM    Rm_1201      Space Temperature    78.0 F
```

- **Use consistent naming conventions** The temperature at the supply fan discharge could be called SF1\_LAT (leaving air temperature) or AHU1\_DAT (discharge air temperature). To avoid confusion, always label like points with similar names.
- **Number points for easy sorting** If there are ten or more of something that is numbered, then number them 01, 02, 03 ... 10. This will give a better sort because most systems will sort 1 through 10 as 10, 1, 2, ..., but would sort 01 through 10 as 01, 02, 03,...
- **Take advantage of upper and lower case letters** Most systems can accept upper and lower case letters for text strings. This can be used to advantage to make things easier to decipher, especially point names where a lot of information is being crammed into a short character string. Consider the following possibilities for the point name for the discharge air temperature associated with air handling unit 1 on a system that allows 8 characters for a point name.

AHU1\_DAT - A good starting point, but may not sort well if the project has (now or in the future) more than 10 air handling systems.

AHU01DAT - This solves the sorting problem, but many would say it was less easily read, especially if scanning it quickly in a long list of similar, nearly identical names.

AHU01\_DT - This may improve readability, but now 5 characters are tied up in describing the system leaving only two characters to describe the data.

Ah01\_Dat - An option that uses upper and lower case letters and a shorter system description to convey the same data in a potentially more readable text string.

Obviously, this is somewhat subjective, but what matters is that the project specifications pave the way for involving the operating staff in the development of the way that the system data presentation is handled and that they be informed about what the possibilities are prior to software and database development. This will allow the operating staff to work with the controls technicians to tailor the system data to their needs.

- **Use engineering units to describe the function of the point** For example, units can be used to differentiate between a command point (on/off) as compared to a point that allows the local control system to start or stop the equipment (enabled/disabled). For instance, the control signal commanding the fan to 50% speed should be labeled to distinguish it from the feedback signal indicating that the fan is actually running at 50% speed.

- **Consider the future** The current project may only have 9 terminal units now, but a future remodel or expansion could add several terminal units. A system set up initially numbering the units 1 through 9 vs. 01 through 09 would encounter sorting problems when units 10 and above were added at a later date. While not a major issue, this sort of thing can be an annoying problem for operating staff and can result in frustration and misinterpretation of data in an operating environment. A little forethought during the early phases of programming can eliminate a lot of frustrations in the future.

### 3.6.2. Virtual Points

Virtual points do not physically exist, but are points that exist in the control system software (see Section [2.3.2 Points List](#) for more details). Virtual points include calculated points, setpoints, and other parameters. The purpose of virtual points is to provide more information to the operator than the raw data can provide alone. For example, chiller load can be continuously calculated by the control system using the chilled water supply and return temperatures and flow rate raw data.

(This is also in BAS Display section). Setpoints and tuning parameters should be virtual points to allow them to be manipulated by the operating staff without having to open up and modify programming code. But often, without specific instruction, the technicians programming the system will simply enter the parameters into the program code as hard values instead of variables that reference virtual points outside of the program for their value. This practice saves some programming time and effort, and, since the programmers are intimately familiar with the programming language and the programs they are writing, there may be little if any utility for them in having the ability to modify parameters without modifying the actual program code. However, the operating staff needs to be able to quickly modify setpoints and tuning parameters when the need arises. With virtual points provided for setpoints and tuning parameters, the operator can make changes without changing the hard coded control algorithms, which is much less risky than making a change to the programming code itself.

The following points are commonly included as virtual points:

- Calculated points such as chiller load, kW/ton
- Temperature and humidity setpoints such as supply air temperature, mixed air temperature, or supply humidity
- Static pressure setpoints like duct static pressure or building static pressure
- Utility system setpoints like chilled and hot water temperature setpoints
- Zone setpoints such as temperature and flow.
- Changeover setpoints like the settings used to enable and disable the economizer cycle or allow humidifier operation.
- PID tuning parameters for all control loops.

### 3.6.3. BAS Settings

**Change of value (COV) limit parameter** In most cases, the controller is working with real time values. These values are filtered for transmission to the operator terminal to keep minor variations from clogging system communications. Usually the COV limit parameter (or a similar function) controls this filtering. The value of the point will not be updated in the operator's terminal until the change in measurement exceeds the limit. If the COV limit is set high, then the reading at the operator terminal may not be a reasonable representation of the

actual system operation. For example, if the COV limit for a space temperature was set to 5°F, the space temperature would not change at the operator terminal unless the temperature changed by more than 5°F or the system was manually forced to read the temperature. COV limit parameters depend on the particular measurement.

**User access** Most systems allow you to control what level different operators can access based on a security level associated with their password. Less skilled operators can be kept from having access at a system level where a parameter could accidentally be changed. Senior staff should be able to access all levels as needed.

Usually, it is desirable to use the system security access features to control who can make changes to these parameters. For instance, junior grade operators may only be allowed to make changes to zone temperatures via the access level associated with their system password. Mid level operating staff may be allowed to change everything that the junior level staff can change and also change central system settings and change over setpoints. Access to loop tuning parameters and critical changeover settings may only be provided to the senior operating staff or the lead facilities engineer.

### 3.6.4. Programmable Alarms

High and low alarms can typically be programmed for any analog point, which can be useful if used properly and annoying if used improperly. Some systems allow a high and low anticipatory alarm in addition to the actual alarm settings. This feature can be very useful on critical parameters to give operators a “heads up” warning based on a trend towards an undesirable operating condition before things get too out of hand. For example, an alarm can be used to anticipate a freeze stat trip.

Floating alarms indicate when a parameter is out of normal operating range. For example, a floating alarm will indicate when the point goes a certain amount above or below a setpoint, even when the setpoint changes due to a reset schedule.

Another useful situation to alarm is when a piece of equipment is in manual override for a period of time. It is easy to forget that an override is in place.

Be sure that the alarms give the information you need, when you need it, for the manner in which you intend to operate your building. Consider these questions as you program alarms:

- **Should the alarm have a time delay?** For example, a 30 second delay in the fan proof of operation alarm will avoid nuisance alarms with the time delay between when the fan is commanded on and when the status point proves it.
- **How will the alarms be prioritized by their importance?**
- **What alarm message should be displayed?** This can be useful for directing a response to the alarm and/or clarifying what is wrong.
- **Which alarms should call a pager?** Does this requirement change with the time of day and day of week?
- **Should the alarm trigger a graphics screen to highlight the alarm condition?** With an event with multiple alarms, multiple triggered graphic screens may clog the system communications and not allow the operators to see what is going on. Often, this problem can be handled with some programming that disables the alarm graphics during certain events. On larger systems, providing a separate alarm printer and alarm monitor dedicated to alarm graphics can alleviate this problem while providing enhanced operating and management capabilities.

**Smart Alarms** Programmable alarms that use information from multiple points and the system's logic capabilities to alert operators to conditions of degraded system performance are called smart alarms. The alarms consist of short algorithms that detect problems through point comparisons. For example, if the preheat coil is active (there is a temperature rise across the preheat coil or the valve has been commanded open) and the economizer is not on minimum outdoor air, then an alarm could notify the operator that energy is being wasted. A smart alarm can alert operators to energy waste by indicating when the outdoor air temperature is below the current discharge air temperature setpoint but the cooling coil is active.

Smart alarms can have great benefit as a diagnostic tool, saving operators' time by automatically detecting problems. As a management tool, the system can be programmed to segregate these more complex alarms to a separate report log directed to the lead operator or facility engineering staff. This practice allows the operating staff up to deal with the day-to-day operating issues and allows the management level staff to prioritize and direct the response to these more complex system performance related issues.

### 3.6.5. BAS Graphical User Interface

A number of issues related to the way in which the BAS graphical user interface is set up can influence the usefulness of the system to the operators. Additionally, providing remote access to this interface is very useful to commissioning providers, operating staff, and the control system contractor, especially during the first operating year. The following issues should be considered for the user interface:

- **Readout accuracy** The display indication should reflect the known accuracy of each measurement device. For example, if a temperature sensor has an accuracy of  $\pm 1^\circ\text{F}$ , then the temperature should be displayed in increments of  $\pm 1^\circ\text{F}$  or  $\pm 0.1^\circ\text{F}$  at the most.
- **Setpoints and Schedules** Setpoints, occupancy schedules, reset schedules, and high/low limits should be variables that can be adjusted without altering the code. To do this, the controls programmer must create system variables rather than hard coding the information. These points should be easily accessed from the graphical interface for editing and comparison to measured values. There are many ways to accomplish this including a table for all systems on the site where the values are displayed and can be modified, or sliders or setpoint adjustment knobs on the system graphic to name a few. This is another area where tailoring the presentation to the tastes of the operating staff early in the programming process can result in a more useful and used system.

At a high security access level, the loop tuning parameters should also be adjustable at the user interface.

- **Operator workstation graphics** In general, the design of the operator workstation graphics should consider two key elements:
  - 1 Allow for rapid, easy to understand and implement, penetration of the building's database.
  - 2 Present the information retrieved in a manner that is easy to understand and interpret by the operating staff.

The graphical user interface for the project can be structured to accomplish this in a variety of ways. The best way to accomplish the intended functions will vary from project to project with the tastes of the operating staff. If the development can be tailored to reflect their tastes, the system will seem user friendly and be more useful to them. If the system is more useful to them, it is much more likely that the building will be

operated at the peak of its performance and efficiency capabilities and that the design intent of the systems will persist. The following items should be considered when specifying and developing the system graphics:

- **Use Building Floor Plans to Guide Database Penetration** Using a graphic of the floor plan is a good starting point for system navigation functions. This screen might include important building parameters like space temperatures and occupancy status. It is often useful to be able to access system graphics from the floor plan view. Most current technology systems can load the architectural and mechanical floor plans directly from the project's AutoCAD files, reducing development time and creating a synergy and consistency between the contract documents and the operating system.
- **Provide System or subsystem graphics** Include a graphic for each system, that displays dynamic operating variables and calculated values related to that system's operation and performance. For large, complex systems, it may be necessary to have a key system graphic that can be used to navigate to subsystems where more operating details are displayed. Ideally, the operators should be able to manipulate setpoints from the system graphic in addition to viewing performance. To facilitate navigation through the system, include links from the system graphics back to the master system graphic, related system graphics and building floor plan. If the project design documents used a systems based approach and include system diagrams or schematics, it is often desirable to develop the control system graphics directly from the contract document information by loading the AutoCAD files of the system diagram to serve as a background for the operating graphics. This will enhance the operator's ability to run the facility by providing consistency and synergy between the building's construction documents and the control system graphics, both of which are important tools in the day-to-day operation of the facility.
- **Develop a Master system parameters Table as a Graphic Screen** Many operators and facilities engineers find that having critical system parameters displayed as a dynamic graphic in a spreadsheet format provides a useful way to get an overall picture of system operation, especially during emergencies and other critical operating situations where calling up multiple system graphics to understand what was going on in multiple systems would take time and focus away from managing the big picture. Including links in the spreadsheet to each system graphic makes it simple to get more detail as necessary. Including the ability to adjust critical system parameters from the table while still keeping the table in view is also useful in managing a critical operating situation.

### 3.6.6. Point Trending

Trending can give facilities staff and commissioning providers valuable insight into how the system is operating. The trending requirements during the commissioning process often are different from the trending requirements associated with the day to day operations of the facility, and may actually set some of the control system performance parameters and dictate the structure of the network. In general, trending for commissioning will require frequent data samples over long periods of time. This may require that the system be set up to archive data from the controllers on a regular basis to maintain a seamless, detailed record of system performance. This is because most systems store trend data at the controllers and then archive it to the host computer at set intervals. If there is not much memory available at the controller, then the trend data needs to be downloaded frequently to the host, or information will be overwritten. Large file sizes or frequent downloads can tie up system communications. Most systems stagger the download times or schedule them for times when

system activity is low. Having this detailed data record available during the commissioning process can be critical in assessing complex system interactions and picking up system performance problems like hunting, which can be masked by less frequent data samples.

Once the system has been commissioned, it is possible and may even be desirable to reduce the trend frequency to minimize the system's data management and data handling burden. This is another area where operator taste and preference come into play. Some operators might prefer to not have to deal with the management of the large quantities of data that are associated with ongoing, frequent trend sample times, electing to keep some limited trending running on critical points and then resetting the system for a more frequent sample rate only when they see a problem. Other operators prefer to take advantage of the relatively inexpensive data storage capabilities of current technology systems that make saving large quantities of data a non-issue. They find that being able to go back into their data archive and take a detailed look at how a system was performing months or years ago can often provide insights into current operating problems. As a result, they implement an archiving procedure that involves saving data to a large hard drive or writing data to CDs or zip disks periodically that allows them to maintain a detailed operating history of their systems. For some buildings that are participating in the US-GBC LEED program, having this ability is a key component of the Measurement and Verification Plan, which can be worth a credit point in the LEED rating system.

### 3.6.7. System Back-ups

Providing a means for backing up the control system database and operating logic is an important but often neglected area in the implementation of DDC control technology. An amazing number of sophisticated systems are specified, furnished and installed without this important capability. In the current technology environment, the cost of this added hardware is inconsequential when compared to the problems that will arise if all or a portion of the system's database is lost or becomes corrupt and must be regenerated. Having a good back up available makes this a relatively short lived, easily recovered from problem. Without a good back up to work from, a facility could be crippled for weeks or even months while the lost database and operating logic is regenerated and re-commissioned.

The bottom line is that the database and operating software of a well-commissioned and well-tuned DDC system can represent an investment of tens or even hundreds of thousands of dollars in a large building. To protect that investment, it is important to:

- **Include the Necessary Hardware and Software Required to Back-up the System in the Project Construction Documents** The first step in a good back-up procedure is to have the hardware and software necessary to do the procedure. Usually, this involves a tape drive, independent hard drive or a CD burner and the software necessary to support the back-up operation.
- **Include Developing a Back-up Procedure and its Associated Requirements as a Part of the Services Provided by the Control Contractor:** Before they leave the site and receive final payment, the control contractor should be required to have developed and implemented a regular back-up procedure for the DDC system. In most cases, a once a week process will be sufficient, especially if it is supplemented by a manually initiated back-up any time significant changes are made to a controller or other system component. Usually it is a good idea to maintain two copies of the system back up, one at the operator workstation location, and one off site. This protects the system from an irrecoverable data loss should a catastrophic event occur at the operator workstation location (like a flood, fire or someone setting a stack of refrigerator magnets on the back-up disks).

- **Train the Operating Staff to Back-up the System as a Part of the Training Program Associated with the Commissioning Process** For the benefits of the back-up procedure and hardware to be realized and persist, the operating staff need to understand the importance of the procedure and be familiar and comfortable with its implementation. For most systems, the process can be automated to the point where it requires very little operator interaction other than to remove and replace the media when necessary and manage the process.

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## 4.1. Introduction

Many different air handling system configurations may be tested using the procedures in the Functional Testing Guide. For each of the twelve system configurations presented, the following information is provided:

- **Description of function**
- **Points list**
- **Appropriate applications**
- **Energy conservation control strategies**

The points lists are intended to be used by designers and commissioning providers as starting points for their own points lists. In a future Design Guide revision, system diagrams may also be provided (similar to Figure 5.1) for each configuration as links to AutoCAD drawings that can be used by designers and commissioning providers as starting points for their own system diagrams.

Users may encounter a system that does not match any of the configurations shown in this chapter. Such a system will likely be a variation on one of the basic systems, and the user should be able to adapt the information to their specific application.

### System Variations

The system configurations begin with a single zone constant volume 100% outside air configuration. All subsequent configurations are recirculating systems with economizers. Systems that use 100% outdoor air are possible in almost all of the configurations discussed in this chapter, but we focus on recirculation systems because they are more typically found in office applications. Although the points list for 100% outside air systems may be somewhat simpler, designers should remember that freeze protection and humidity control become even more critical in air handlers that use 100% outside air.

A number of the air handling systems presented in this chapter must reheat the supply air to offset perimeter loads. Alternatively, any of these systems could use hydronic heat for the perimeter loads instead of the ducts, dampers, and controls associated with an all-air reheat system. Using hydronic perimeter heating can often be more easily implemented and controlled than reheating air. Perimeter hydronic heating also has the potential to be more comfortable than warm air due to radiant heating effects. As a result, space temperatures tend to run lower for equivalent comfort, and less reheat is required. Eliminating the reheat element pressure drop also saves fan energy, but this may be balanced by the pump energy of the heating water system.

The systems configurations in this chapter may require a return or relief fan if they recirculate air, however, the addition of these fans does not affect the system configuration. The pressure drops associated with the return and relief paths determine if the fans are required to avoid over-pressurizing the occupied zone due to the restriction created by the return and relief system. Additional discussion of this topic can be found in *Chapter 20 Return, Relief and Exhaust*. The examples below will assume the return or relief fans are required in order to demonstrate their impact on the point lists.

### Static Pressure Safety Points, Limit Switches, and Permissive Interlocks

Static pressure safety points and limit switches have more to do with the outdoor air and life safety requirements associated with a system than the HVAC process it provides. The

following three systems are examples of how the system size and configuration can affect the safety points installed:

- A 100% outdoor air constant volume system rated for capacities in excess of 15,000 cfm and equipped with a fan capable of developing significant static pressures. There would typically be an inlet damper that closed when the system was not operating to isolate it from the external environment. In turn, these dampers may cause the designer to consider some combination of limit switches, static pressure safety switches and permissive interlocks to prevent the fan from starting with the dampers closed and damaging the fan casing or duct system.
- The above 100% outdoor air system that is rated for less than 15,000 cfm would most likely not require smoke isolation dampers. However, the designer still may apply safeties to protect the inlet system and fan casing from problems associated with the failure of the inlet damper to open.
- For an economizer system rated for less than 15,000 cfm with return ducts and a return damper, the designer may rightly deem the system safe to operate without any static pressure related interlocks or safety systems.

In short, the safety point functions will tend to be independent of the HVAC process associated with the system. Since the point lists associated with this chapter are related to the HVAC process, they will not reflect every safety point associated with smoke isolation or 100% outdoor air configurations. To illustrate these concepts, the Single Duct, Single Zone, Constant Volume System point list includes the points associated with protecting the intake system and fan casing from excessive negative pressures due to a failure of the inlet damper. The Single Duct Variable Volume Reheat System has been configured to reflect a system with smoke isolation requirements and the associated safety interlocks.

## 4.2. System Descriptions and Points Lists

For each system configuration described in this chapter, there is a corresponding points list that can be used as a starting point for creating your own points lists. Information for the control contractor regarding application of the points can be found in the footnotes of the Points List Spreadsheet. The last column in the spreadsheet, *Design Guide Supplementary Notes*, contains a more detailed explanation of point application specifically for designers and commissioning providers. At the end of each system description in this section, the points list is compared to a previous list. Within the Points List Spreadsheet, these differences are listed in **bold** type. Table 4.1 gives an overview of the points lists provided in the link below:



Points List  
Spreadsheet

*Link to an Excel spreadsheet of the points lists indicated in Table 5.1 below.*



Points List Explanations

*Link to a document that contains the Points List Explanation notes referenced in the last column of the Points List Spreadsheet.*

**Table 4.1 Points List Overview**

<b>System Configuration</b>	<b>Tab in Excel Spreadsheet</b>	<b>System Reference</b>
<b>Constant Volume, Single Zone, 100% Outside Air</b>	CV SZ	
<b>Constant Volume, Single Zone with Economizer and Return Fan</b>	CV SZ econo & return	
<b>Constant Volume with Reheat</b>	CV Reheat	
<b>Constant Volume with Bypass Variable Volume</b>	Bypass VAV	
<b>Variable Air Volume with Reheat</b>	VAV Reheat	
<b>Hybrid Constant and Variable Volume Systems</b>	None	VAV with reheat
<b>Constant Volume Multizone</b>	CV MZ	
<b>Variable Volume Multizone</b>	VAV MZ	
<b>Texas Multizone</b>	Texas MZ	
<b>Three Deck Multizone</b>	3Deck MZ	
<b>Dual Duct Constant Volume</b>	DD CV	
<b>Dual Duct Variable Volume</b>	DD VAV	
<b>Dual Duct Dual Conduit</b>	None	Building envelope loads system: VAV; Internal loads system: Constant Volume Reheat
<b>Low Temperature Air</b>	None	VAV with reheat
<b>Natural Ventilation</b>	None	No mechanical cooling for pure natural ventilation, various applications for mixed mode systems.

### 4.2.1. Single Duct, Constant Volume, Single Zone

Figure 4.1 illustrates a typical single duct, constant volume, single zone air handling system. This air handling system is probably one of simplest configurations possible since there is no terminal control equipment. Most residential air handling systems are of this configuration. In a sophisticated application, the system can still have some complex components. The preheat coil in the figure can see large quantities of subfreezing air, requiring that special design steps be taken to prevent it from freezing. The constant volume pumped coil approach shown is one of many solutions to this particular design issue. Depending on the capacity of the system and the use of an economizer, the return/exhaust/relief fan may not be necessary.

More information regarding this particular system configuration can be found in: *2000 ASHRAE Handbook, Heating, Ventilating, and Air Conditioning Systems and Equipment*, Chapter 2, American Society of Heating Refrigerating and Air Conditioning Engineers, 1791 Tullie Circle, N.E., Atlanta Georgia 30329, 404-636-8400, [www.ashrae.org](http://www.ashrae.org).



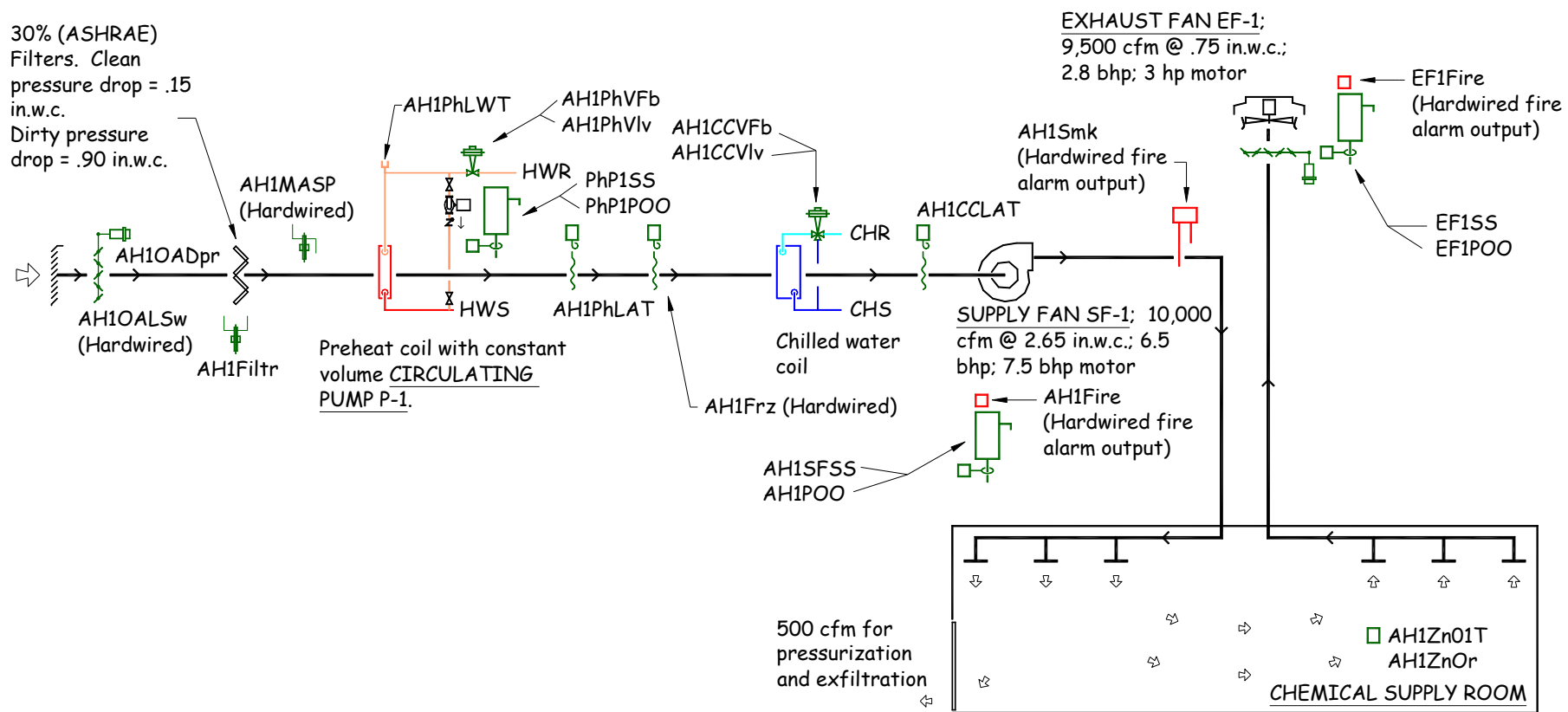


Figure 4.1 Typical Single Duct, Constant Volume, Single Zone Air Handling System



### Single Duct, Constant Volume, Single Zone with Economizer

With an economizer, the single zone constant volume system requires the following additional points:

- Return air temperature
- Mixed air temperature
- Return air damper command and damper feedback (proof of operation)
- Relief air damper command and damper feedback (proof of operation)
- Relief air control point (outdoor/return damper signal or building static pressure signal)  
For constant volume systems, having the relief air dampers track with the economizer dampers will usually work reasonably well unless the building is excessively leaky. For additional information on this topic see the related discussions in *Chapter 9: Economizer and Mixed Air*.
- Minimum outdoor air damper command and feedback (if applicable)
- Zone CO<sub>2</sub> Level (if applicable)
- Manual override capability for the unoccupied cycle. The owner may desire a simple way for the zone occupants to override the operating schedule regardless of whether or not a facility operator is on site. Refer to Section [3.4.2 Manual Override](#) for details regarding how to implement this function.

### Single Duct, Constant Volume, Single Zone with Return or Relief Fan

For systems with a return or relief fan, the single zone constant volume system can include the following additional points:

- Return/relief fan start/stop command and feedback
- Return/relief fan hours of operation
- Smoke detector and/or fire alarm interlocks will be required for the return or relief fans in most instances
- Return/relief fan capacity control command and feedback. In the event that the relief dampers are not controlled by the same signal as the economizer, the return fan will need capacity control.

## 4.2.2. Single Duct, Constant Volume, Reheat

A typical single duct, constant volume air handling system with reheat delivers a fixed volume of cool supply air to multiple zones and reheats this air as demanded by the thermostat in each zone. The supply air temperature is set low enough to meet the zone with the highest demand for cooling. Terminal equipment at each zone consists of a set of steam, hot water, or electric reheat coils controlled by the zone thermostat. Constant volume with reheat provides comfort control for zones with unequal loads and is often used for applications with close temperature and/or humidity tolerances. In some instances, recovered energy can be utilized for reheat to minimize the energy intensity of the process.

The energy intensity associated with this process can be reduced by setting the minimum outside air flow appropriately for all zones. Constant volume reheat systems tend to require reheat for all zones if the minimum outside air flow has been set too high.

Energy can also be minimized by incorporating a strategy to reset the system supply temperature based on the cooling demand of the zone with the highest load. In a properly operating resetting routine, the zones at or equal to the maximum demand for cooling will be the only zones that are not being reheated. To make sure that air temperature is reset as high as possible during cooling mode, compare reheat valve positions. At least one reheat valve should be nearly closed. Values of 95 to 98% closed are common when using this routine. If the discharge temperature was reset until a valve was fully closed, then there would be no way of knowing if the zones in that state were satisfied or actually starting to overheat and required additional capacity through lower supply temperatures. The bottom line is that this approach minimizes the energy burden associated with a constant volume reheat system by keeping at least one zone on the verge of running out of cooling capacity.

Even with the reset strategy, the reheat process results in high energy use. Supply air temperatures in the system are generally set based on the sensible heat ratio in the space and the associated humidity control requirements. Air volumes are then determined based on this supply air temperature and the design load in the space. Since the spaces seldom see the full design load, any excess capacity must be used up in the reheat process to avoid overcooling the zone. There are several energy implications to this reheat process.

- The cooling plant provides cooling that is reheated, in addition to the cooling that is required to meet the load in the space. Thus, the cooling plant tends to run at a constant load factor even though the load is varying.
- The fans must deliver a constant volume of air based on the design load condition at a temperature based on dehumidification requirements in the space on a design day.
- The heating plant, including boilers, pumps, and any other related equipment must run any time the reheat air handling system is operating if temperature control is to be maintained. This is true even in the summer, because reheat energy is required to prevent the zones from overcooling.
- In the winter months, for reheat zones that serve perimeter areas, the supply air must be reheated to make up for the initial cooling of the air and then heated further to meet the any heating loads.

In an efficient constant volume reheat system, the supply air temperature should be reset based on the maximum demand for cooling, but during moderate cooling loads, a raised supply air temperature could result in problems with humidity control. Therefore, the reset schedule needs to include an upper limit. A lower limit is also desirable to prevent an errant zone or inappropriate operator command from lowering the set point beyond what is necessary to properly dehumidify the air.

If the system under consideration is a true constant volume reheat system, then the distribution system pressure or flow requirements for different zones will not usually vary.<sup>1</sup> As a result, the zone control system requires no flow regulation and simply consists of a thermostat and the reheat valve. The most cost effective way to provide this function is usually with a stand-alone pneumatic, electric, or electronic thermostat. However, installing a DDC controller to perform the zone control functions can have benefits that often justify the added costs. Benefits of DDC control include:

---

<sup>1</sup> This should be very carefully considered during the design process. Installing unnecessary constant volume regulators adds an on going energy burden to the system due to their static pressure requirement. It also adds complexity and first cost due to the flow regulation and control requirement associated with it. This added complexity will ripple out into the operating life of the building as a higher maintenance cost.

- Zone valve position and temperature data become available from a central location. This provides the following benefits that are useful for commissioning and ongoing operations.
  - 1 Faster response to comfort problems.
  - 2 Mitigation of comfort problems in critical areas before they become issues by using alarm settings.
  - 3 Documentation of performance for quality control purposes or to demonstrate compliance with specified zone temperature requirements through trending functions.
- Many current technology DDC terminal unit controllers have the capacity beyond what is required for basic control functions. These spare points can be used to provide energy conservation and improved performance in the following ways:
  - 1 Monitoring of the reheat coil discharge air temperature for commissioning and diagnostic purposes. For example, an alarm can be generated if the reheat valve is commanded fully closed but there is still a temperature rise across the reheat coil due to a leaking valve.<sup>2</sup>
  - 2 For systems serving zones with radically different operating schedules, a spare output can be used to control two position dampers in the branch ducts serving the different areas to shut down the air flow when the zone is unoccupied. This function is similar to a two-position VAV system. To be effective, this feature needs to be combined with at least one of the following measures to prevent the flow eliminated in one area from simply moving to other zones.
    - A variable speed drive at the supply fan controlled to maintain a constant pressure at some point in the duct system. This is usually the most cost effective approach because it maximizes the fan energy savings at a minimum of cost.
    - If the fan can tolerate being pushed up its curve, installing constant volume regulators on the zones will allow them to control flow as well as temperature. This usually is more costly than installing a variable speed drive unless there are only a few zones. In addition, the ongoing maintenance of the flow control loops adds complexity to the system.

**Single Duct, Constant Volume with Reheat - Additional Points compared to Single Duct, Constant Volume, Single Zone System with economizer and return fan:**

- Reheat valve command and feedback
- Discharge air temperature per reheat valve
- Alternate configuration (points not included in example points list below): Zone flow control to allow flow to portions of the areas served by the system to be shut down when they are unoccupied while other areas remain in operation. Usually, this feature requires some form of capacity control at the air-handling unit, or some sort of volume regulation at the zones as discussed previously. These requirements add some points in addition to the point controlling the shut down damper.

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<sup>2</sup> Measuring the temperature across the reheat coil is not as simple as it sounds, so judicious application to the larger zones may be more viable than application to all zones. To be effective, the initial and ongoing commissioning process needs to perform a relative calibration between these sensors and the main discharge air sensor to ensure that an indication of a temperature rise is truly a temperature rise and not a false indication due to sensor calibration accuracy issues. In addition, duct temperature rise needs to be accounted for in some manner. And if the discharge sensor is located ahead of the fan, the fan heat also needs to be accounted for.

### 4.2.3. Single Duct, Constant Volume, Bypass VAV

The single duct constant volume with terminal unit bypass is a slight variation on the constant volume reheat system. Instead of terminal reheat coils, the constant supply flow is varied to meet the cooling load in the space by diverting some of the air directly to the return plenum or duct, thus bypassing the space. Injecting supply air directly into the plenum can pressurize the plenum and cause the return air to flow back into the space. For this reason, the return plenum in bypass systems must be kept at a lower pressure than the occupied space. Return fans may be necessary to attain this low plenum pressure. Constant volume bypass VAV systems can be more energy efficient in cooling and heating modes than constant volume reheat systems since the bypass air reduces the return air temperature during cooling mode and increases the return air temperature during heating mode. As a result, the cooling or heating at the air handler is reduced. However, since a constant volume of air is moved through the space, fan energy is not saved compared to a conventional VAV system, which can often be much more significant than the heating or cooling energy.

The terminal equipment applied with this system can be very similar or identical to the terminal equipment associated with a conventional VAV system and can include reheat capability. For additional information on these terminals refer to Section [4.2.4 Single Duct VAV with Reheat](#). The point requirements for VAV terminals applied in the bypass VAV system configuration will be similar to those described in Section [4.2.4](#).

#### **Single Duct, Constant Volume, Bypass Variable Air Volume - Additional or replacement points compared to Single Duct, Constant Volume Reheat System:**

- Return plenum pressure differential to zone pressure. Several sensors may be required if the plenum is subdivided by smoke or fire separations due to the pressure drops created by flow through the transfer ducts.
- Bypass air damper command and feedback. Some systems use a common bypass damper, while others bypass at the zone level with the same actuator that controls the terminal damper. To check against bypassing too much air, in cooling and heating modes, at least one bypass damper should always be fully closed. Otherwise the discharge air temperature set point could be increased (for cooling) or reduced (for heating).

Since the zones in this application are variable air volume zones, each zone requires all of the points associated with variable air volume operation.

- The least point-intensive approach to VAV systems is to provide pressure-dependent VAV operation. These terminal units will require damper and reheat control (may need reheat in addition to the bypass during minimum flow) and a space temperature sensor as an input.
- Pressure independent control requires the same points as pressure-independent control plus a flow input from a flow-measuring element on the terminal unit intake.

## 4.2.4. Single Duct VAV and VAV with Reheat

The single duct variable air volume (VAV) system controls temperature by varying the supply air flow rate to each zone. Air flow is varied by modulating dampers at the terminal units, or VAV boxes. Variable volume systems are more energy efficient than constant volume systems, especially when loads vary across zones. Since each zone is supplied with the minimum amount of flow necessary for cooling or ventilation, the total airflow demanded is greatly reduced compared to constant volume systems. A fan capacity control mechanism<sup>3</sup> reduces the supply air flow and saves energy.

If perimeter heating loads are addressed by an independent perimeter heating system, like finned tube radiation, fan coil units, or radiant slabs, then it is often possible to achieve temperature control simply by varying air flow. In situations where the perimeter heating loads must be served from the VAV system, or where the ventilation requirements (and thus, the terminal unit minimum flow settings) are high, it will probably be necessary to provide reheat coils on many of the terminal units and operate the reheat system all year. Zones with less demand for cooling limit the flow through their VAV boxes, then reheat the supply air if the minimum flow exceeds space cooling demand. The reheat process in a VAV system adds energy, but it is far less significant than the reheat associated with a constant volume system. Using recovered energy from the refrigeration system condenser circuit to serve the reheat requirements in the summer can mitigate this energy burden to some extent.<sup>4</sup>

New VAV boxes are commonly pressure independent, with a flow sensor at the inlet of the box that regulates the zone airflow based on the zone temperature. Pressure dependent boxes, an older VAV technology, operate without this flow sensor. Instead of controlling the damper based on the measured air flow, the damper in a pressure dependent VAV box modulates based directly on the zone temperature. In this case, the flow varies with duct static pressure and is more difficult to control. In all cases, the terminal units are set up to provide some minimum flow level required for ventilation purposes, even if the airflow is not needed to serve the load during lightly loaded conditions. For pressure dependent systems, minimum flow is achieved simply by a limit on the minimum damper position. For pressure independent systems, a minimum flow set point must be met.

Instead of changing the supply air temperature (the only temperature control mechanism for the constant volume system), the variable volume system maintains a fixed supply temperature for similar outdoor air conditions. Although the VAV system does not need to change supply air temperature, for energy savings and comfort control, the supply air temperature can be reset based on ambient conditions or some other indicator. When supply temperature reset is used, the supply temperature is decreased in the summer to meet high cooling and humidity loads and increased in the winter to match the lower cooling loads and reduce reheat energy.

However, supply temperature reset needs to be applied with caution on VAV systems since it can counteract the variable flow operation, resulting in reduced fan energy savings and often

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<sup>3</sup> Typically, the fan capacity is controlled using a variable frequency drive, inlet guide vanes, variable blade pitch, or discharge dampers. All of these approaches will save the fan energy associated with the flow reduction, although some strategies save more energy than others. For smaller systems with low peaks on their fan curves, the complexity associated with these fan capacity control approaches may not be warranted when compared to simply allowing the VAV terminals push the fan operating point up the curve. Pushing the fan operating point up its curve is also the process provided by a discharge damper, the least desirable of the capacity control mechanisms due to the low fan energy savings potential and the impact the damper can have on the fan's performance due to system effect.

<sup>4</sup> Sellers, David and Tom Stewart, "Making Energy Intensive HVAC Processes More Sustainable via Low Temperature Heat Recovery", Proceedings of ACEEE 2002.

nearly constant volume operation. Increasing the supply temperature setpoint so that the fan does not reduce speed is undesirable since the fan energy savings usually outweigh the heating and cooling energy savings achieved by the temperature reset.

Heating can be accomplished through hot water, steam, or electric reheat coils (with or without a fan-powered VAV box), or by circulating warm return plenum air using fan-powered or induction VAV boxes. In some situations where the loads served have high internal gains and the ventilation requirements are relatively low, reheat is not necessary during the summer months if some discharge temperature reset is provided. In these situations, reheat can be accomplished by using the perimeter heating system during the winter, spring, and fall months. Eliminating the reheat coils and the piping network and controls associated with them has the following benefits:

- Reduced first costs and operating costs
- Reduced potential for energy waste via unnecessary reheat due to inappropriate settings or valve leakage.
- Parasitic losses associated with operating the reheat system during warm weather are eliminated.
- Fan energy is saved since the reheat coil pressure drop has been eliminated from the system.

More information regarding this particular system configuration can be found in:

ASHRAE Systems and Equipment Handbook, 2000, p. 2.10.

#### **Single Duct Variable Volume with Reheat - Additional Points compared to Single Duct, Constant Volume System with Reheat:**

- Supply and return/relief fans motor speed command and feedback (compare for VFD diagnostics)
- Drive selector switch status
- VAV box flow
- VAV box discharge air temperature

### **4.2.5. Hybrid Constant and Variable Volume Systems**

In large systems or systems that have undergone renovation, it is not unusual to find a combination of constant volume and variable volume zones in a single air handler. Health care, laboratory, and process applications are particularly prone to this configuration. In general, the central system portion of these air handling arrangements will look schematically identical to a VAV system with similar point and control requirements. The zone portion of the systems will appear to be schematically identical to the VAV zones with the constant volume feature achieved by operating the VAV terminals at a fixed volume. Usually the fixed volume is accomplished by setting the maximum and minimum flow settings of the VAV box to the same value, but it can also be accomplished using mechanical flow regulators that have no external control connections.

Regulating the constant volume flow is necessary to ensure that the flow and pressure variations created in the system by the operation of the VAV terminals do not cause flow variations in the constant volume areas. Without the flow regulation, the flow variations produced in the constant volume zones will tend to be above design flow since the system was probably balanced for design flow at maximum capacity. As the VAV terminals reduce

flow, excess flow would occur at the constant volume zones. These flow variations can cause several problems.

- The excess flows in the constant volume zones lead to even greater reheat loads (and the related parasitic loads) than would be seen if the constant volume flow was regulated, thus energy is wasted.
- The excess flows reflect fan energy that could be saved if the constant volume flows were regulated, thus energy is wasted.
- The excess flows in the constant volume zones can create pressure relationship problems between the constant volume zones and their surroundings. Without regulation on the constant volume zones, pressure relationship problems can be difficult to control and diagnose since they vary with the operation of the VAV terminals. Even with regulation on the constant volume loads, there can be pressure relationship problems that occur as the VAV terminals in surrounding areas operate. However, regulating the constant volume zones minimizes this potential. Additionally, if the flow regulation is provided with DDC technology, then the potential exists to write control algorithms that modify the constant volume parameters based on the current state of the air handling system as a field solution to a pressure control problem that may occur down the road.

Point requirements for these systems will be similar to those associated with the single duct VAV and single duct VAV reheat systems, as described in Section [4.2.4 Single Duct VAV with Reheat](#).

## 4.2.6. Constant Volume and Variable Volume Multizone

### Overview

The traditional multizone includes separate ducts for the heating coils and cooling coils, traditionally called the hot deck and cold deck, respectively. The discharge of the air handler is divided into a number of zones via a zone damper assembly. For each zone, the full cold deck, the full hot deck, or a mixture of the two airstreams can be supplied - as the cold deck damper closes, the hot deck damper opens. The dampers modulate to provide a supply air temperature that adequately serves each zone's heating or cooling load. The air is distributed by a single dedicated duct to each zone.

Multizone systems are often served by packaged air handlers that supply only up to sixteen zones, but these systems are cost-effective compared to built-up air handling systems. The traditional two-deck multizone cools and heats air that is supplied to a single zone, which is a reheat function that is not allowed by many energy codes. This issue is addressed by the three-deck multizone discussed in Section [4.2.8](#).<sup>5</sup> Although traditional multizones do have some reheat, multizones (without precooling coils) do not cool all of the supply air, since some of the supply air is diverted to the heating coils. As a result, multizone systems are more thermally efficient than constant volume reheat systems, which cool all of the supply air

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<sup>5</sup> An interesting and unusual variation on this approach has been observed where a chilled-hot water coil was installed in the traditional cold deck position, and the hot deck was simply a bypass of the cold deck. When outdoor conditions were not suitable for cooling, the chilled-hot water coil was served with chilled water and the temperature control function was achieved by mixing air discharged from the cooling coil with air that bypassed it. In this mode, the bypass air was very near the return temperature since the system was recirculating and only bringing in the minimum outdoor air required for ventilation. When outdoor conditions were suitable for economizer cooling, the chilled-hot water coil was served with low temperature hot water, the action of the thermostats was reversed and the traditional cold deck became the hot deck and the bypass deck became the cold deck, served by economizer cooling.

before reheating it as necessary. However, multizone systems are not as flexible as constant volume reheat systems for future reconfigurations since the zone configuration is based on the air handling unit configuration at the zone control dampers.

Multizone systems can be a low first-cost method of serving different loads in a number of zones and have the advantage of placing all of the zone equipment at the air handling unit location (except for the Texas Multizone, discussed in Section [4.2.7 Texas Multizone](#)). This configuration lends itself to applications with a limited number of multiple zones where the zone requirements and configurations are unlikely to change over time.

The constant volume multizone supplies multiple zones with different loads using a constant volume fan. In most instances, this is accomplished with a single fan, but there are designs that utilize a fan for each deck for energy conservation purposes. In many ways, these designs are schematically similar to double duct systems.

The energy efficiency of a multizone system can be improved by adding a variable volume feature. The zone dampers can be delinked with independent actuators for the hot and cold deck dampers associated with each zone. The zones are then controlled to modulate the cold deck damper to a minimum position that will guarantee the required ventilation flow prior to opening the hot deck dampers. If the flow at the minimum cold deck position results in the space being overcooled, then the hot deck damper is allowed to modulate open as required to maintain temperature.

### **Installing and Commissioning Multizone Systems**

Through the process of mixing hot and cold air streams at the air handler for each zone, thermal efficiency is lost due to significant heat transfer between the hot and cold decks at the air handler and leakage through the deck dampers. Over time, damper linkages must be well maintained to minimize this leakage. For larger building areas, extensive ductwork is required to supply air to remote spaces. Duct leakage along this distance should be minimized, since the leakage wastes energy and may result in uncomfortable conditions as remote zones are supplied a reduced amount of air.

Since the entering condition to both decks of the multizone is the mixed air condition for recirculating systems or the preheat coil leaving condition for 100% outdoor air systems, coordinating the economizer control or preheat control with the hot and cold deck control is important from an energy efficiency and performance standpoint. For a recirculating system operating on an economizer cycle, the depressed mixed air temperature (relative to the return air temperature) places an extra heating load on the system for any air that serves the hot deck, compared to serving the hot deck directly with return air. Thus, maintaining an economizer set point that is as warm as possible, perhaps based on the cooling demand, will minimize the reheat penalty at the hot deck.

Multizone units with high percentages of outdoor air which are located in humid environments often use a precool coil upstream of the hot and cold decks. Without a cooling coil upstream of the hot deck, all air passing through the hot deck to the zones will be at a specific humidity determined by the mix point for the return air and outdoor air. For a 100% outdoor air system or a system in economizing mode, the hot deck can be 100% outdoor air. Integrating the economizer cycle with the operation of the cold deck capacity control needs to be used with caution since the air going out to the loads through the hot deck may not pass through a cooling coil and thus may not be dehumidified. Similarly, on a 100% outdoor air multizone unit, the preheat function should be coordinated with the control of the cold deck so that the preheat coil does not heat air any higher than the requirement of the cold deck.

Deck temperature reset routines targeted at maximizing the cold deck temperature and minimizing the hot deck temperature can be particularly important for multizone units from an energy conservation standpoint for several reasons:

- These routines will minimize the heating energy in the hot deck and cooling energy in the cold deck.
- The closer the deck temperatures are, the lower the thermal losses will be from the air from a zone at full cold deck flowing past the fully closed, but warm hot deck damper blades as the air passes through the zone dampers. Similar effects will be minimized on zones demanding full hot deck.
- The thermal losses through the hot deck casing will be minimized.

For multizone systems serving internal zones, it may be possible to reset the hot deck temperature as low as the return temperature since there is no need to heat the internal zones. Multizone units serving perimeter zones can also use return air in the hot deck once the outdoor conditions rise to the point where the zone is experiencing a net heat gain. In most buildings, this occurs somewhere between 60 and 70°F outdoor air temperature unless there are extensive areas of glass. Perimeter zones that have an independent perimeter heating system can also use this approach to hot deck reset.

In order to have a reasonable control response, the pressure drop through the hot deck and cold deck needs to be nearly identical. This is often accomplished by using a smaller coil in the hot deck section since the hot deck coil will typically be shallower than the cold deck coil and will never be wet. Some systems also have a baffle plate in series with the coil to tune this pressure drop relationship. These arrangements can produce high static pressure losses that translate to a constant fan energy penalty.

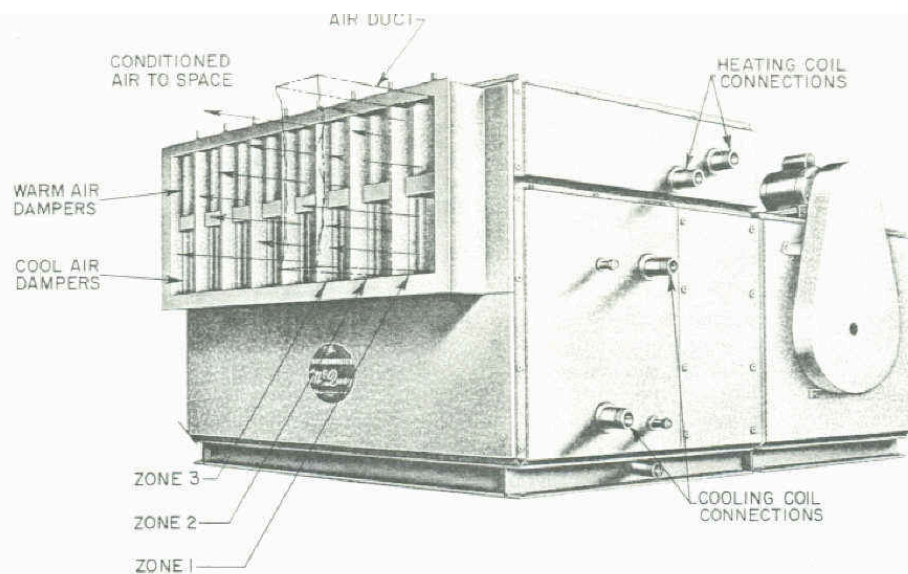


Fig. 40: Multizone Air Conditioning Unit.  
Photo Courtesy of McQuay Inc., Minneapolis, Minn.

**Figure 4.2 Multizone Unit**

#### **Constant volume multizone - Additional or replacement points compared to Single Duct, Constant Volume, Single Zone System with Economizer and Return Fan:**

- Preheat coil leaving air temperature is the hot deck temperature
- Preheat coil leaving water temperature is the hot deck coil leaving water temperature
- Cooling coil leaving air temperature is the cold deck temperature
- A unit with a high percentage of outdoor air may require a preheat coil and/or a precool coil ahead of the fan. (Add a preheat leaving air temperature sensor, valve command, and feedback and/or a precool leaving air temperature sensor, valve command, and feedback) These configurations are not included in the points list below.
- Mixing damper position command and feedback for each zone
- Zone temperature feed back (to zone dampers)

#### **Variable Volume Multizone - Additional or replacement points compared to Constant Volume Multizone**

- For each zone, a hot deck damper command and feedback independent from a cold deck damper command and feedback

### **4.2.7. Texas Multizone**

The Texas multizone, designed to serve hot and humid climates, is a modification of the traditional two deck multizone unit. In hot and humid climates, the cold deck air typically must be overcooled for adequate dehumidification. Return air (typically called the neutral deck) is used instead of an actual hot deck to provide some reheat for each zone. The use of return air as the first stage of reheat saves energy compared to the traditional multizone configuration. Additional heating is provided by independent reheat coils in the individual zone ducts, often at a location near the zone they serve. The zone reheat valve is modulated open after the zone dampers are in the full return air position. Placing the reheat coils in the individual zone ducts saves energy by ensuring that only the air for the zone with a heating demand that cannot be met by the return air will use additional reheat.

Since there is not heating coil in the hot deck, all air flow resistance required for creating an equivalent pressure drop through the hot deck compared to the cold deck is provided by a baffle plate.

#### **Additional or replacement points compared to Constant volume multizone:**

- Hot deck temperature is replaced by mixed air temperature
- Perimeter zone reheat valve command and feedback
- Leaving air temperature from zone reheat coil. Use for commissioning and troubleshooting.

## 4.2.8. Three Deck Multizone

The three deck multizone adds a neutral deck (mixed air) between the cold deck and hot deck. Through the zone damper configuration, cold deck and hot deck air are not allowed to mix. The neutral deck air is mixed with the cold deck or hot deck air to meet the space requirements. In this way, there is no reheat energy used. Full neutral deck air can also be supplied for low heating loads. Like the Texas multizone, using return air for reheat is a heat recovery function, which makes this strategy more energy efficient than the traditional multizone.

The neutral mixed air condition can be much different than neutral return air, especially if the unit requires a high outside air percentage and is located in a hot and humid climate. In these cases, the humidity of the neutral and hot decks may be too high to meet space conditions. The cold deck can be overcooled to reduce its humidity further, or the outdoor air can be pre-cooled to reduce the latent load of the mixture of outside and return air that supplies the hot, neutral, and cold decks. In this way, the neutral deck can be used to temper the cold deck air to meet the space condition required at each zone without increasing humidity to inappropriate levels. This precooling configuration adds a reheat function to the three-deck multizone if the hot deck is utilized during times that pre-cooling occurs.

### Three deck multizone - Additional or replacement points compared to Constant volume multizone

- Mixing damper position for each zone (one damper linkage for three decks)
- Neutral deck temperature

## 4.2.9. Dual Duct Constant Volume and Variable Volume

### Overview

Dual duct systems consist of a hot supply air duct and a cold supply air duct that run throughout the building to each terminal unit. This configuration is similar to a multizone, except mixing does not occur at the air handler, but at a mixing box at each zone location. Dual duct constant volume systems maintain a constant volume of air to each zone terminal unit, and vary space temperature by changing the fraction of hot and cold air that is mixed. Since the hot and cold decks may have different static pressures, controls must be used to maintain a constant flow through each terminal unit. The temperature of the hot deck can be reset higher in the winter and lower in the summer to save reheat energy. If heating loads are low enough and the system has two fans, return air can be utilized in the hot deck instead of the heating coils. Similar to traditional constant volume multizone systems, dual duct constant volume systems lose thermal efficiency due to the cooling and reheating process that occurs to maintain space temperature. Dual duct constant volume systems are an improvement over constant volume reheat systems since not all air passes through both the cooling and heating coils, thus some reheat energy is saved.

Dual duct variable volume systems are more efficient than dual duct constant volume systems because the cold deck and hot deck airflow can be modulated at each zone based on the zone thermostat. As a result, fan power and reheat are reduced, since the volume of air to the space can be reduced to a minimum before the hot deck air is introduced.

Both constant volume and variable volume systems can utilize a single fan for both the hot and cold ducts or two fans, one for each duct. When a single fan serves both ducts, the mixed

air (mix of return and minimum outdoor air for ventilation) is sent through both the heating and cooling coils. Thus, the ventilation air can lead to increased hot deck reheat energy compared to full return air, and the single fan configuration may not be conducive to economizer use. With separate hot deck and cold deck fans, the hot deck can draw from the return airflow directly, while the cold deck can draw from the outside air as necessary for economizing. The thermal energy savings can make up for the potential increase in fan power from the two fans.

### **Installing and Commissioning Dual Duct Systems**

In this section, the challenges in installing and commissioning dual duct systems for energy efficient operation are discussed.

In order to use the hot deck for only reheat and avoid sizing the hot deck for perimeter loads, most dual duct systems have reheat coils at the perimeter zones to handle the envelope losses. In the dual fan case, the minimum flow for ventilation must come from the cold deck since the hot deck is pure return air. In this way, for zones with heating loads, the reheat is similar to a VAV or constant volume reheat system.

The dual duct system has nearly twice as much sheet metal as you would for other approaches since you end up running two ducts, each one of which must be sized for more than 50% of the air flow, and generally end up being the same size. Even if the ducts were sized for 50% air flow each, there would still be more metal used in the duct system at an equivalent friction rate due to perimeter vs. cross-section issues. (For instance, two 12 x 12 ducts have 8 feet of perimeter and can not carry as much air as one 12 x 24 duct, which has 6 feet of perimeter.)

All of this extra ductwork creates congestion in the ceiling cavity. When tapping the ducts for a terminal unit, one duct will cross the other; i.e. if you connect on the cold deck side, then the hot deck connection has to cross over or under the cold deck to get to the terminal unit. A solution to this problem is to put the supply ducts up high and the terminals down low and tap the bottom of the duct. However, most buildings do not have enough ceiling space to do this.

From a control standpoint, the dual duct system is more complex, especially with the dual fan. For instance, you have one return fan that has to track with two VFD supply fans. In addition, the hot deck fan must never move more air than the return fan; otherwise, it will pull mixed air into the hot deck portion of the system. Designing the controls to make the system work under all operating modes is not easy.

At the terminal unit, similar control problems can exist. Two dampers must be controlled for correct minimum and maximum air flow and space temperature. Dual duct systems can waste energy when hot and cold deck dampers at each zone do not fully seal, creating a false load and unnecessary heating or cooling. Commissioning and maintaining the damper close-off positions on possibly hundreds of dual duct terminal units can be a difficult task.

### **Single Fan Dual Duct Constant Volume: Additional or replacement points compared to Constant Volume Multizone system**

- Mixing damper command (at the zone instead of at the air handler)
- For any terminal units with supplemental perimeter heating with reheat coils, similar to constant volume reheat system (not shown in points list)

### **Dual Fan Dual Duct Constant Volume: Additional or replacement points compared to Single Fan Dual Duct Constant Volume**

- Start/stop command output and proof of operation input for both hot deck and cold deck fans.

### **Dual duct variable volume: Additional or replacement points compared to Variable Volume Multizone system**

- Motor speed command and feedback (compare for VFD diagnostics)
- VAV box flow
- VAV box discharge air temperature

## **4.2.10. Dual Duct, Dual Conduit**

### **Overview**

The dual duct, dual conduit system is a subtle variation of the dual duct dual fan approach that provides supply air for building envelope loads separately from internal loads with two separate supply conduits (supply ducts). The hot deck in a dual duct, dual fan system may use mixed air or full return air, and therefore is not decoupled from the outside air. The dual duct, dual conduit configuration creates a separate system that can be tailored to the needs of the perimeter loads, which will be a heating load part of the year. The second system can be tailored to the needs of the interior, which will generally have a year round cooling load. These systems have frequently been high velocity systems that used induction units<sup>6</sup> for the terminal devices and served high-rise buildings.

Since the perimeter load condition varies with the season, the temperature of the supply air for the envelope loads usually is varied based on ambient conditions. In many applications, independent perimeter systems are provided for each face of the building. This configuration allows the supply air temperature for each face to be tailored to the current load conditions. For instance, a building with a lot of glass on a sunny winter day may actually require cooling on the perimeter on the South face for a portion of the day, but require heating on the perimeter on the North face at the same time. In some arrangements, the perimeter terminal equipment can be an all-air system. In other arrangements, the perimeter terminals consist of reheat coils or chilled-hot water coils. Systems with chilled-hot water coils could be operated in many modes including:

- Supply cold air to the terminals with chilled water in the coils for supplemental sensible cooling on peak days
- Supply cold air to the terminals with hot water in the coils for operation more along the lines of a constant volume reheat system for days when some zones, but not all zones might require some heat while others were a net cooling load.
- Supply warm air to the terminals with hot water to the coils for peak heating loads.

Many times, the hot water system supply temperature is operated on a reset schedule based on outdoor ambient conditions.

The supply air system that serves internal cooling loads and ventilation loads for dual conduit system is cool year-round since, in theory, an internal space will never see a net energy loss if it is surrounded on all sides by conditioned spaces. In the past, induction terminals that mimic current technology VAV and VAV reheat systems served the interior zones. Many of

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<sup>6</sup> Induction units are discussed in more detail in *Chapter 19: Terminal Equipment*.

the older versions of this system have been converted to current technology VAV and VAV reheat systems to reduce the operating static requirements.

In a variation on this system, one conduit or duct system is heating-only, utilizing return air and a heating coil while the other is capable of cooling and handles the conditioning of the ventilation air. In this configuration, the envelope and the internal zones that require reheat terminate in a dual duct mixing box and the system tends to operate like a dual duct system.

### **Installing and Commissioning Dual Duct, Dual Conduit Systems**

There are some operational and commissioning issues that are unique to dual conduit systems. Terminal units that were equipped with chilled water coils typically had a small drip pan that was intended to collect any minor condensation that occurred when chilled water was in the coil. Generally, these pans were not piped to drain (hence the name drip pan vs. drain pan). While in theory this is reasonable, since the ambient air dew point should have been reduced by the central system, infiltration through the envelope on the perimeter can cause locally high dew points resulting in condensation problems that overwhelm the drip pans and cause water damage. This problem is most prevalent in older high-rises with leaky envelopes located in humid environments. It can be especially pronounced if the building is operated on a schedule and pressurization is not maintained overnight. When this occurs, the stack effect or other phenomenon that can make the building negative, like a continuously operating exhaust fan with no positive make-up air source, fills the building with humid air during the shutdown period. Then, when the systems are restarted, they must deal with a dehumidification load, and, if chilled water is introduced into the perimeter system coils, the dehumidification occurs there, often with disastrous results in terms of water damage. This usually terminates any efforts at operating the building on a schedule, much to the detriment of its energy efficiency.

This problem usually can be mitigated in the following manner. If not all of the central systems are shut down and the cooling plant remains in operation, then the systems that stay on line will hold the dew point of the building at the intended level, eliminating the start-up dehumidification load and associated condensation problems. In most cases, the systems can be operated in a pure recirculation mode (no minimum outdoor air) to conserve energy. However, introducing some outdoor air will help pressurize the building and may prove beneficial in terms of avoiding localized condensation at start-up due to localized infiltration of the envelope.

From an energy approach, this method of unoccupied operation will use more energy than simply shutting everything down because it requires operating enough air handling capacity to adequately circulate some air through most of the building in some manner. But this can often be accomplished by running only a few of the systems because the real issue is controlling the vapor pressure in the building, not the temperature, and the water vapor will migrate to the area of lower vapor pressure even if there is no active air flow forcing it in that direction. It also requires operating the cooling plant at a low load condition. But, experience has shown that operating in this manner will prevent the water damage problems if the systems that remain on line are carefully selected. And since the energy used to keep these systems running with the chiller plant at low load is often less than the pull down load that occurs if the building fills with humid air during the off cycle.<sup>7</sup> Thus, as an alternative to not shutting anything down during hot and humid weather, it offers an attractive method to achieve some of the fan energy savings available via scheduled operation without risking

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<sup>7</sup> When the building fills with humid air, the moisture content of the moisture absorbing materials in the building increases. To bring the building back under control, all of this moisture needs to be pulled back out of the materials and shows up as a part of the pull down load, just like the thermal energy that ends up being stored in the building elements when they are allowed to warm-up over night.

damage to the building finishes and the subsequent termination of any scheduled operation. Savings can still be significant since fan energy is a major constituent of the overall energy consumption pattern of many buildings, often several times the consumption of the cooling plant.

**Building envelope loads system:** Single duct VAV

**Internal loads system:** Constant volume with reheat

## 4.2.11. Low Temperature Air

Low temperature air systems have the opportunity to reduce costs – both annual operating costs and first costs. The principle behind this system is that by supplying air between 45°F and 48°F instead of the typical 55°F supply air, the volume of air supplied can be greatly reduced. Low temperature systems can reduce supply air volume by 30%-40%. The fan energy savings and other benefits must be weighed against any increases in energy and other drawbacks to decide if a low temperature air system is appropriate for a given application.

The reduction in air flow requirements translates into a number of related benefits:

- **Reduced fan power** A smaller fan motor can be selected, and/or the VFD will have greater turn down. It also may be possible to eliminate the return fan. Lower fan horsepower also reduces fan heat in the supply air stream.
- **Smaller air handlers** Smaller duct sizes and reduced coil face area will decrease the footprint of the air handler. The area needed for vertical air shafts is also reduced.
- **Smaller ductwork** In cramped spaces above the ceiling, smaller ductwork makes installation easier. The space savings from smaller ductwork can also lead to shorter floor-to-floor height.
- **Smaller terminal units** Smaller terminal units are cheaper and save space above the ceiling.

Lower supply air temperatures result in lower room relative humidity, which has the following benefits:

- **Indoor air quality** Less potential for growth of mildew and mold due to the reduction of condensation. To achieve this, the building envelope needs to have low infiltration. Slightly positive pressurization is an effective way to achieve this; rather than humid air infiltrating, dry air exfiltrates.
- **Longevity** Building materials and finishes are likely to last longer with reduced humidity.
- **Raise space temperature setpoint** Lower humidity allows a higher temperature setpoint for equivalent comfort. To avoid dumping cold air on occupants, low temperature air systems typically use high-aspiration diffusers that increase room air mixing and diffuser throw. Fan-powered VAV terminal units can also be used to improve mixing with constant fan operation during occupied hours.

While the overall system often saves energy, a number of aspects of the low temperature air system reduce this total savings. Designers should be aware of the following energy increases in their calculations of system energy consumption:

- **Chilled water system efficiency** Low temperature air systems rely on low flow (high delta T) chilled water systems, which tend to increase energy chiller energy slightly. Producing colder water (leaving chilled water temperatures of 42°F to 38°F) can reduce

chiller efficiency by 6%-10%. Efficiency can be improved by selecting a chiller precisely for the desired chilled water temperature. To further optimize the chillers, the actual load profile must be used to optimize the chiller part-load efficiency. This actual load can be difficult to predict during design. If actual loads are variable, there may be a mismatch between the load profile that the chillers have been optimized for and the load profile that the chillers will actually see.

- **Cooling energy** With a low temperature air system, significant dehumidification occurs that is not necessary to meet a typical space design condition. The lower humidity levels mean larger cooling loads for an equivalent zone temperature setpoint. Less air is being conditioned to this lower humidity, so the fan energy savings can offset or partially offset this increased cooling and dehumidification energy.
- **Reheat** Compared to a traditional 55°F supply air system, the low temperature system will cause zone reheat to increase if the minimum air for ventilation has greater cooling capacity than the load in the space requires; zones reheat 41°F air rather than 55°F air. Resetting the amount of ventilation air based on actual ventilation requirements can minimize the reheat loads, although this strategy requires a means of sensing and controlling outdoor air flow and a method of detecting occupancy (typically CO<sub>2</sub> sensors). These items add complexity to the system and must be well maintained for persistence of savings.

Even if the spaces do not run at minimum flow with reheat in the summer months due to the loads on them, they will run at minimum flow in the heating mode. If chilled water was not being used for cooling in any of these zones, then the supply air temperature could be raised to avoid excess reheat. Raising the supply temperature may be difficult because different zones will transition into the heating mode at different times depending on their exposure and loading.

- **Economizer cooling hours** Using low temperature supply air means that the chillers have to run until the outdoor air temperature is below 41°F instead of 55°F. In moderate climates, this difference can translate into thousands of hours per year of additional chiller plant operation.
- **Condensation** In moderate climates, buildings do not typically need to be kept pressurized or dehumidified overnight<sup>8</sup>. In these moderate climates, the outside air dew point can be greater than the low temperature system supply air temperature. If the building is shut down overnight or over the weekend, the stack effect and the difference between the vapor pressure inside and outside can fill the building with outside air. Since this outside air has a higher dew point temperature than the supply air temperature, condensation problems can occur during start-up. The cold supply air can cool the diffusers and other objects below the dew point of the outside air that infiltrated into the building, with resulting condensation damage and indoor air quality problems. Operable windows also represent a path for outside air to enter the building and cause condensation problems upon start-up.

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<sup>8</sup> In hot and humid climates, the building must be kept dehumidified and slightly pressurized during all hours of the cooling season to guard against condensation problems.

## 4.2.12. Natural Ventilation Cycle

The systems previously described consist of mechanical equipment for heating, cooling, and ventilation for commercial buildings. Buildings can also be designed to provide comfortable thermal conditions without using air handling equipment, or only using the equipment for part of the year. Natural ventilation is a low-energy approach to fully meet ventilation requirements and fully or partially meet cooling requirements. Airflow in a natural ventilation cycle may rely on the stack effect, operable windows, wind pressure, wind driven ventilators, or other pressure effects. When the outdoor air is cooler than the air in the building, the stack effect causes warm air inside the building to rise and exit at the top levels and colder, more dense outdoor air to enter at the lower level. The neutral plane can be raised to the top of the building by creating a venturi as the air exits the top floor. Natural ventilation is a site-specific way to bring in outside air for cooling and ventilation without using mechanical energy.

If the natural ventilation cycle cannot meet cooling requirements, an air handler can take over. When natural ventilation and mechanical ventilation systems are implemented together, it is often referred to as a *mixed mode* system. Due to their highly customized nature, natural ventilation and mixed mode strategies are not specifically covered in this Guide, but commissioning the components of these systems, such as dampers and actuators, are covered. Thus, a commissioning practitioner faced with a project that includes such a system should be able to develop a test plan by assembling the necessary components from the information presented.